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LIFE SUPPORT AND ENVIRONMENTAL PROTECTION STUDIES

1ST QUARTERLY PROGRESS REPORT

29 APRIL, 1960

R. A. NAU
C. D. KING
M. M. MAHMOUD

ENGINEERING RESEARCH REPORT

CONVAIR-SAN DIEGO   CONVAIR DIVISION   GENERAL DYNAMICS CORP.

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research program Number 9023.

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I. SUMMARY

This study of life support and environmental protection for manned space vehicles has the objectives of identifying and developing advanced concepts, and establishing design criteria for manned vehicle systems. In order that the study results will be readily applicable to Convair's participation in manned space vehicle programs, the work of the first quarter includes a survey of such program planning by civilian and military agencies of the Government. The planned missions serve as a reference framework for the study. Concurrent tasks have been studies of environmental hazards and life support requirements, and an assessment of the U. S. technological level in environmental protection and life support. As a result, it is possible to identify problem areas and select those of maximum interest to Convair.

Planning of manned space missions includes both research and military categories, and both are dependent in their time phasing on the development of boosters. The boosters considered and their estimated operational dates are Atlas-Agena (1960) Atlas-Centaur (1962), Saturn (1964), and Nova (1968). The manned missions prominent in planning are: boost glide reconnaissance vehicle; earth orbital bomb launch platform; manned space ferry; military test space station; recoverable booster; space laboratory; space logistics, maintenance and rescue vehicle; advanced Mercury; and soft moon landing and return. Convair's Spaceplane concept is sufficiently versatile for application to many of these missions.

A closed ecological system is one in which the wastes of metabolic processes are reclaimed for human intake. This requires separation of O_2 from CO_2, and processing feces and urine to obtain food and water. In a completely open system, wastes are separated and stored or discarded; and all intake requirements must be stored on board or re-supplied. Partially closed systems appear optimum for missions of the next decade. In particular, reclamation of water from wastes appears feasible at present, but separation of O_2 from CO_2 is considerably more difficult and conversion of feces to food is not promising for space applications.

Environmental aspects which require design provisions for protection or control are vacuum, radiation, meteorites, temperature, zero-g, acceleration, vibration, and acoustic noise. Cabin design must minimize leakage of the internal atmosphere. The radiation hazard will require shielding unless a trajectory may be chosen to avoid exposure. Meteorite protection is significant primarily in avoiding loss of gas-tight integrity of the cabin wall. The temperature control problem is amenable to analysis and may be met by suitable combinations of surface characteristics, heat flow paths, insulations, radiators, and active or passive control techniques. The remaining environmental aspects impose problems in cabin design and progress in these areas may be expected from the current Mercury Program.

Recommended problem areas for continued Convair study are: leakage of cabin atmosphere; CO_2 separation and reduction; integration of environmental control and life support with other subsystems; modular design of life support and environmental control equipment; and determination of power requirements for the processes involved. These areas offer greatest promise of benefit to Convair.

The work reported herein is a study performed during the first four months of 1960, under REA 9023. This work is part of a one year effort which has the purpose of providing environmental data and design criteria which will enable Convair to participate competitively in manned space programs. Participating personnel were R. A. Nau, C. D. King, and M. M. Mahmoud, of the Thermodynamics Group; W. E. Woodson, D. W. Conover, and C. H. Purdy, of Human Factors, who prepared parts of Sections V, VI, and VII; and Dr. R. C. Armstrong and Dr. W. L. S. Wu, of Aerospace and Radiation Medicine, who also contributed material of Section VI. Acknowledgement is made of the cordial cooperation of the Astronautics and Fort Worth Divisions in providing results of their related studies.

III. PROCEDURE AND SCOPE

A. Background of Related Work at Convair

Listed below are closely related studies that have been performed recently by the various Divisions of Convair.

1. Astronautics, REA 111-9030: R. M. Garcia-Varela and J. C. Ballinger, "Environmental Control Study of Space Vehicles (Part I)", Report Number ERR-AN-004, Aerophysics, 9 March 1960.

2. Astronautics, REA 111-9027 and REA 111-9123: D. E. Meister and R. B. Wilson, "The Role of Man in Earth Satellites", Report Number AZG-006, Reliability-Human Engineering, 11 February 1960.

3. Astronautics, REA 111-9121: "Reflectivity of Materials". Work in progress.

4. Astronautics: Work performed for Astronautics by Ionics, Inc., 152 Sixth Street, Cambridge 42, Mass., "Study of Environmental Requirements for Manned Space Vehicles", 17 November 1959.

5. Astronautics: Krafft A. Ehricke, "A Systems Analysis of Fast Manned Flights to Venus and Mars", 11 March 1959.

6. San Diego: R. A. Nau, "Environmental Control Systems for Manned Space Vehicles", ASME Paper No. 59-AV-11, presented Aviation Conference, 9-12 March 1959.

7. San Diego, REA 8349, PSA 2306: R. A. Nau, Proposal to NASA, "Life Support System Design Study for Manned Space Vehicles", 8 September 1959.

8. San Diego, REA 8329: C. D. King "Self-Sustaining Rankine Cycle Cooling System Feasibility Study" 20 May 1959. 7/- - 7/J

9. San Diego REA 9364: Proposal to WADD in response to PR 92069, "Space Vehicle Thermal and Atmospheric Control Study", Report Number ZR-760-016, 30 March 1960.

10. Fort Worth, REA PR-14 7: "Thermo Systems Research, Environmental Study", Report not yet released.

11. SLOMAR: A Convair proposal was submitted with Astronautics as the lead Division for a Space Logistics, Maintenance, and Rescue Vehicle Study. It is planned that, if a contract is awarded, the San Diego Division effort will include the Life Support and Environmental Control Systems, Report Number AE 60-0216, 14 March 1960.

12. MTSS: The Military Test Space Station proposal included basic studies of Life Support and Environmental Control Systems, and experimental work on these and related subsystems. As above, the San Diego Division would support Astronautics in the areas mentioned. Report Number AE 60-0217, 21 March 1960.

B. Procedure

The study sequence listed below was followed through the fourth step during the first quarter of work. Information was obtained by literature search, visits to government and industrial establishments, and attendance at technical meetings.

1. Mission Study

Probable manned missions and their estimated calendar schedules were determined so that this study would have maximum applicability to these missions.

2. Space Environment Study

Data of natural and induced environmental characteristics were assembled for use in establishing design criteria.

3. Technology Survey

Progress in research and development toward environmental control and life support systems was assessed.

4. Selection of Critical Problem Areas

Those problem areas offering greatest promise and most amenable to Convair effort were chosen for further study.

5. Intensive Study of Selected Problems

Analyses, design studies, and limited experimental work will be performed during the remainder of this program.

C. Scope

The time scale considered for this study is to 1970. Only manned missions are considered, and the "space environment" is construed to include atmospheric flignt during boost and re-entry. Emphasis is on man's physiological requirements and the means by which these requirements may be met with least penalty to the vehicle. It is assumed that within the next ten years the mission duration for any individual or crew will not exceed 30 days, and that vehicles of longer life will have a crew rotation schedule.

IV. MANNED SPACE MISSION PLANNING

A. Booster Performance Summary

The information outlined below is from several sources, among which are some inconsistencies. Its purpose is to predict capabilities in the time phasing of manned space missions. These data are believed to be current, and will be revised whenever new information is available.

Booster	Atlas	Titan	Saturn	Nova
Thrust, lb.	300,000 +	300,000 +	1,500,000	6-9,000,000
Operational Date (estimated)	1959	1961	1964	1968
Upper Stages	Agena (1960) Centaur (1962)			
Approximate Payload Capability, lb.:				
Earth Orbital, period=90 min.	9,000	9,000	37,000	290,000
24 Hour Satellite	2,500	2,500	11,000	60,000
Circumlunar	3,000	3,000	13,000	100,000
Moon Landing	1,000	1,000	8,000 (no return)	9,000 (return vehicle)

B. Proposed Missions

The listing here indicates the spectrum of manned space vehicles most prominently considered for development during the next decade. From this list, one or more may be selected to serve as analytical models for environmental control and life support system studies, at which time the most recent vehicle data will be used.

1. Boost Glide Reconnaissance Vehicle. Atlas or Atlas-Centaur class booster.

2. Earth Orbital Bomb Launch Platform. Saturn class booster.

3. Manned Space Ferry. Atlas-Centaur.

4. Space Laboratory. Atlas-Centaur or Saturn class booster.

5. Military Test Space Station. A version of the space laboratory. Atlas-Centaur or Saturn.

6. Recoverable booster.

7. SLOMAR (Space Logistics, Maintenance and Rescue). A version of the manned space ferry. Atlas-Centaur, Saturn, or recoverable booster.

8. Moon Landing and Return. Nova.

9. Advanced Mercury. Atlas class booster.

C. Spaceplane

This is a manned vehicle which would fly from ground to orbit and then return to base with all hardware intact. The versatility of Spaceplane would permit it to perform many of the missions listed above.

D. Nuclear-Powered Flight

If nuclear energy is applied to manned space flight, a new class of missions, and of problems will come into consideration. The propulsion capability will make possible flights of long duration, such as in exploration of other planets. The long mission duration will greatly intensify nearly all of the problems in life support and environmental protection. It appears improbable that missions of this class will occur within the next decade.

E. Estimated Time Phasing of Manned Missions

The table below is the best current estimate, and will be revised as new information becomes available.

Booster	Mission	1962	1964	1966	1968	1970
Atlas Class.	1		X			
	3				X	
	6		X			
	9	X				
Saturn	4		X			
	7			X		
	2			X		
Nova	8					X
Electrical Prop.						?
Spaceplane						X

F. Selection of Analytical Models

Duration of the manned space flight is the most significant single variable in analysis of life support and environmental control requirements. For this reason, it is appropriate to establish short duration and long duration categories and select a mission from each for study. Tentatively, the range of 3 hours to 72 hours will be defined as a short duration mission, and long durations will be in the range of 3 days to 30 days. It will thus be assumed that a continuously orbiting vehicle has crew rotation and resupply at intervals of 30 days or less. Within this framework, a tentative selection of missions to serve as analytical models is as follows:

1. Short Duration: Spaceplane.

2. Long Duration: Space Laboratory.

V. DEFINITION OF SPACE ENVIRONMENT

A. Natural Environment

1. Radiation

(a) Electromagnetic (Solar). Total radiant energy at the top of Earth's atmosphere averages slightly more than 0.2 watt/cm^2 of which 0.14 watt/cm^2 is direct solar energy with a spectral distribution as follows:

Radic	0.3 cm	10 meters		
Infrared	0.7 "	10 "	0.0715 watt/cm^2	(51%)
Visible	3800 Å	7000 Å	0.0575	(41%)
Near UV	2000 Å	3800 Å	0.0105	(7.5%)
Far UV and Soft X-Ray	1 Å	2000 Å	0.00028	(0.2%)
Hard X-Ray and Gamma	10^{-4} Å	1 Å	?	?

Data on electromagnetic radiation in space are reasonably adequate for design purposes. No significant degradation due to photon exposure of structural materials is expected. However, more complete information on the intensity, spectral distribution, and absorption characteristics of hard UV and solar X-rays in space is needed should it be necessary or desirable for men and equipment to operate outside the protective walls of the space vehicle.

A few representative examples of the direct or indirect effect of electromagnetic radiation on life support systems for manned space vehicles are:

Infrared: Engineering of temperature control systems for sealed cabins or other enclosures provided for the astronaut.

Light : Vision of the human eye in observation, navigation, etc. Auxiliary power units using solar energy. Closed ecological systems using solar light.

UV and
X-Rays : Interference with radio communications through ionosphere.

(b) Particulate Radiation. An evaluation of the biological risk of exposure to ionizing radiation in space, based upon data available to the early part of 1960, is given in ZR 659-057. Subsequent information provided by Explorers VI and VII and Pioneer V (out to 10^6 miles from Earth) indicate that radiation levels are within 2% of previous measurements taken within the vicinity of Earth and do not change the conclusions of the study. The potential radiation hazards of the natural environment to manned space missions are, (1) the acute exposure of a space crew to protons trapped in magnetic fields of Earth (or other planets), or emitted from the sun during periods of high solar activity, and (2) chronic exposure to galactic cosmic radiation when missions are extended in time and space. On the basis of current knowledge, the radiobiological risk to space crews for protracted periods of exposure will be within acceptable limits at orbital altitudes below 600 km and between a latitude region roughly equivalent to 40°N and 40°S.

(1) <u>Van Allen Radiation*</u>. It is generally agreed that, except for very brief periods, the inner zone of trapped particles will be uninhabitable for manned orbiting vehicles. The extent of the inner trapping zone, and the relative intensities of spiralling particles, are essentially constant in time varying less than 20%. The radiation hazard arises from the small but biologically significant proton component of sufficient intensity and energy (50-400 Mev) to produce dose rates as high as 1 r/hr** even after penetrating several millimeters of lead (or about 4 gm/cm^2). The lower limits of the zone show a longitude dependence - from 400 km above the central Atlantic to 1200 km above Singapore; maximum intensity of inner region occurs between altitudes of 2000 km to 6000 km above the equator. The outer zone of trapped particles begins at about 12,000 km above the equator, with maximum intensity at about 16,000 km. falling off steadily to a normal cosmic ray background at about 60,000 km. Particle flux in the outer Van Allen region is characteristically of low energy - predominantly electrons, with only about 1 $proton/cm^2/$ sec of energy greater than 60 Mev. Average dose rates on the order of 1 r/hr through 1 gm/cm^2 material thickness are most probably delivered by secondary X-rays through electron interactions. A manned vehicle in a 24 hour orbit within the trapped particle region will require added shielding for missions lasting more than a day or so. For deeper penetration into space, rapid escape through the Van Allen zones will result in an integral dose of about 10 r within a lightly shielded vehicle. Assuming a similar dose on the return to Earth and no acute high exposures to solar particles, the total mission dose may be considered an acceptable risk.

The physical effects of exposure of radiation-sensitive elements to the unattenuated flux of charged particles will possibly have some direct or indirect bearing upon life-support equipment. Trapped radiation at full intensity will produce dose rates estimated from 1000 to 10,000 r/hr, sufficient at continuous exposure to eventually cause radiation damage to unprotected plastics and solar battery surfaces.

(2) <u>Solar Flare Particles</u>. Ionizing particles arriving at the top of atmosphere (over the polar caps and high latitudes) have been detected a few days after intense solar activity but beyond the vicinity of Earth localized regions of solar particles will probably be unpredictable - or perhaps giving only a few minutes warning to crews operating in space. The intensity of solar protons in the range of interest from 70 Mev or less to several hundred Mev falls off more rapidly (as E^{-5}) toward higher energies than do trapped protons, but the biological effects and shielding problems are comparable. Solar electrons have

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* J. A. Van Allen "Analysis of Space Radiation Phenomena", delivered at Manned Space Stations Symposium, 21 April 1960, Los Angeles, California.
** r/hr = Roentgens/hr.

not been detected at high enough energies or intensities to
present a shielding problem. The characteristic features of
solar particle storms are, (1) frequency of occurrence which
is apparently related to the 11-yr sun-spot cycles, averaging
about 1 per month during periods of intense solar activity,
(2) relatively brief duration at maximum intensity, (3) essen-
tially unidirectional flux showing a very strong latitude
dependence in the vicinity of Earth, and (4) the unknown
spatial distribution of solar-particle storms beyond more
than 10 Earth radii. The highest intensity of solar particles
occurred in February 1956 when ionization dose rates from
10-50 r/hr lasting for about a day were estimated at the top
of the atmosphere. In 1959 during a solar event, maximum
ionization (measured at high latitudes through 1 gm/cm^2)
reached 500 times normal cosmic ray background for a few hours
then decreased by a factor of 10 every 4 hours. Explorer VII
equipment, monitoring continuously for 6 months recorded only
1 event exceeding twice normal. On April 1st event, count
rates increased more than a hundredfold for a few seconds at
a distance of 30,000 miles from Earth and about 30 times
normal cosmic ray intensity beyond the trapping fields. Van
Allen estimates that there may be perhaps 100-1000 solar
particles/cm^3 of low energy in interplanetary plasma and
believes that solar protons may possibly be a major hazard
but only beyond vicinity of Earth.

(3) <u>Primary Cosmic Radiation.</u> Information obtained from recovered
nuclear emulsions exposed at balloon altitudes, and from rocket
and satellite instruments has indicated that density of primary
cosmic nuclei beyond the influence of Earth's magnetic field
averages about 2 particles/cm^2-sec from all directions in space.
Hydrogen nuclei (protons) account for about 80-85% of the total
flux; helium nuclei 13-15% and nuclei of elements from lithium
through iron about 1%. The primary cosmic particles are pre-
sumably of galactic origin and have characteristically high
kinetic energies, in a wide spectrum from about 500 Mev/nucleon
to as high as 10^6 or 10^8 Mev/nucleon with intensity varying
approximately as $E^{-1.5}$ or $E^{-1.8}$. The lower energy nuclei are
deflected by the geomagnetic field and do not ordinarily pene-
trate below the inner Van Allen zone. At altitudes greater
than 6400 km dose rates average about 0.025 rad/day, varying
as much as 100%. Little is known about the biological effects
of such high energy particles, but the potential hazard to
humans would appear to be insignificant as compared to other
risks of space travel, particularly for exposure times on the
order of days or weeks. Of radiobiologic concern however is
the statistical probability however slight - that a heavy
nucleus not removed by interaction with vehicle structures
may penetrate the human body at low enough energy to produce
dense ionization which in turn may irreparably damage or
destroy cells vital to body functions.

2. Meteoroids

(a) <u>Nature of Meteorite Hazards.</u> A manned space vehicle will be subjected to constant bombardment by meteorites. These bodies will vary from minute molecular particles which tend to sandblast the skin of the vehicle and ultimately destroy its optical and thermodynamic surface properties, to larger bodies which will penetrate the cabin wall and may result in the loss of the life-sustaining oxygen.

Meteorites constitute the randomly orbiting debris of the solar system. Some of them which follow rather well-defined orbits are known as showers. The largest concentration of meteorites is around the ecliptic plane and thus interplanetary trips should be conducted above or below this plane to minimize meteoroid encounters.

The usual orbits of meteorites are highly eccentric and thus they can assume velocities as high as 42 km/sec. The relative velocities of meteorites striking earth vary from those corresponding to head-on collision, in the direction of motion of earth, of 71 km/sec to those corresponding to the Earth's escape velocity of 11 km/sec when a meteorite catches up with Earth from behind, the Earth's orbital velocity being about 30 km/sec.

Most meteorites orbit around the sun in the same direction as the Earth and other planets. It is thus beneficial for interplanetary vehicles to follow the same direction to minimize high velocity collisions.

The problem of assessing the nature of meteorite hazards may be divided categorically into two parts:

(1) Estimating the frequency of encounter of meteorites as a function of their dimensions, mass and kinetic energy.

(2) Estimating the effect of collision between meteorites and the exposed surfaces of space vehicles.

(b) <u>Mathematical Description of Meteoritic Flux.</u> Present knowledge of meteoritic flux is based on visual, photographic and radio observations coupled with some recent satellite tests which are so sparse that they should be considered as inconclusive. Whipple's latest data, which are based on visual and photographic observations, represent the best source available.

Whipple assumes a mean striking velocity v = 28 km/sec for brighter meteorites to 15 km/sec for faint ones. A visual magnitude value, M_v of zero was assigned to meteorites with a mass m of 25 gm. The mass of meteorites striking Earth was estimated at 54 tons per magnitude per day. A simple distribution law was employed to express the number of meteorites as a function of mass. The relation between mass and visual magnitude was expressed as:

$$m = 25 \ e^{-0.921 \ M_v} \tag{1}$$

Now, if N is the number of meteoritic hits per square foot per year, then it follows from Whipple's data that:

$$N = 7.74 \times 10^{-8} \, e^{\, 0.921 \, M_v} \tag{2}$$

A linear relation between mass and visual magnitude as given by Whipple is:

$$V = 35 - M_v \qquad \text{cm/sec} \tag{3}$$

From equations (1) and (2), it is seen that

$$M_v \propto \frac{1}{m}$$

then

$$N \propto \frac{1}{m}$$

or $Nm = \text{constant}$ $\tag{4}$

This expression holds true for any of the known explanations of meteoritic flux encounters. A plot of N versus m for all the published estimates is shown in Figure 1, after Bjork and Gazley. It is interesting to find that the upper limit of this plot is 3000 times greater than the lower limit. This illustrates the associated degree of uncertainty regarding both the mass and flux of meteorites. However, Whipple's data seems like a rough average of various estimates and thus constitutes a good working model in the absence of more precise information. A deviation of an order of magnitude will be expected. Figure 2, taken from Whipple's data, shows the number of meteorites striking Earth per day as well as the number striking a near-Earth vehicle.

(c) <u>Phenomenon of Meteoroid Penetration.</u> Most of the early estimates of meteoroid penetration were based on hypervelocity impact data obtained in the laboratory. All data dealing with the impact of single particles lay in the velocity range below 5.2 km/sec.

Explanations of the impact phenomenon differ widely. However, it is agreed by most researchers that energy is released over the minute impact area and that the ratio of penetration depth to the diameter of meteorite is a function of some power of the impact velocity, or, $\frac{p}{d} = v^n$. When the volume of the crater is considered proportional to the kinetic energy of the projectile the value of n is found to be $\frac{2}{3}$. But, if it is held that the crater

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MASS & FREQUENCY OF METEORITES STRIKING EARTH

FIGURE I

METEOROID FLUX (WHIPPLE'S DATA)

Number / ft² / day on near-earth space vehicles

Number striking earth per day

Visual Magnitude, M
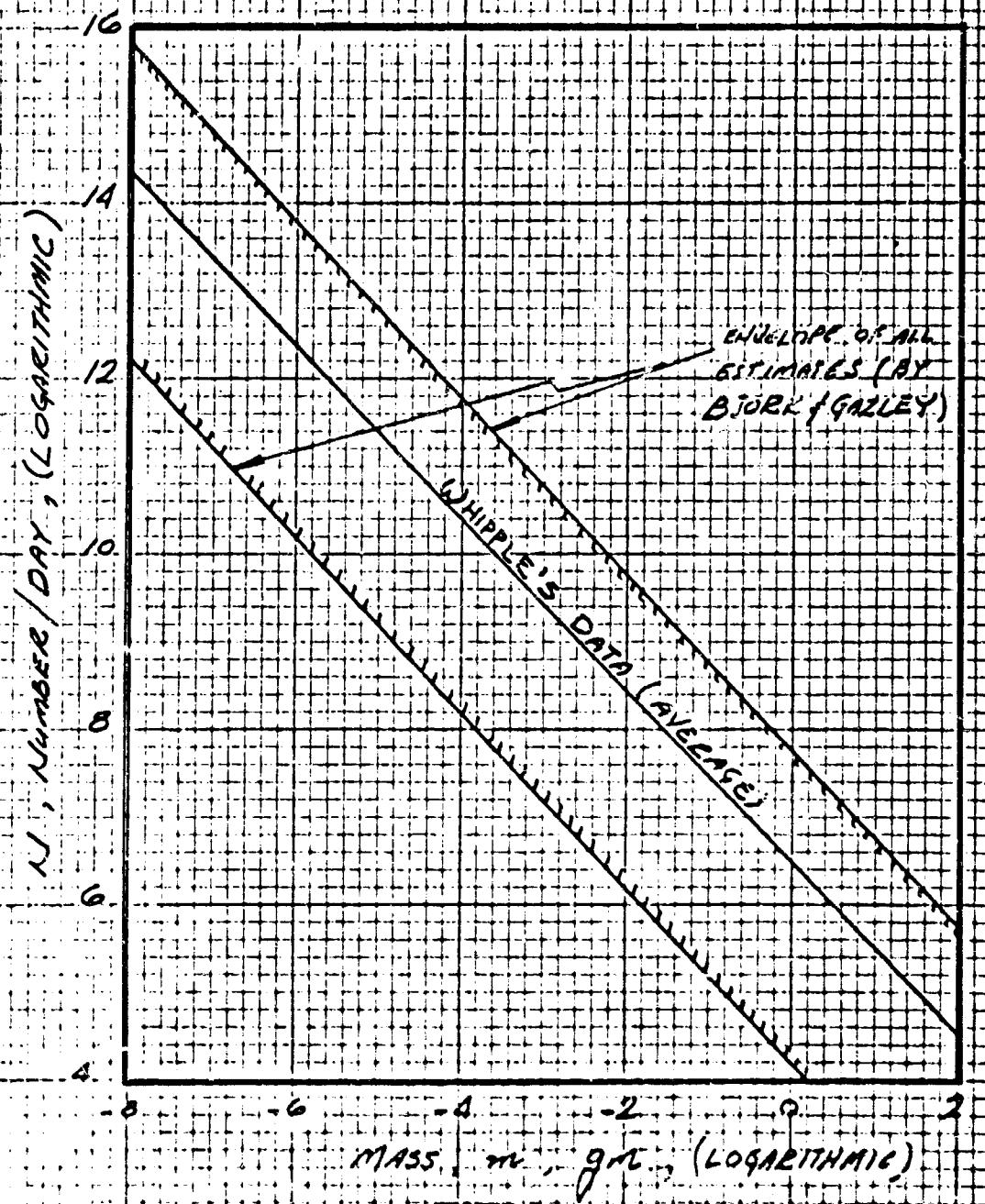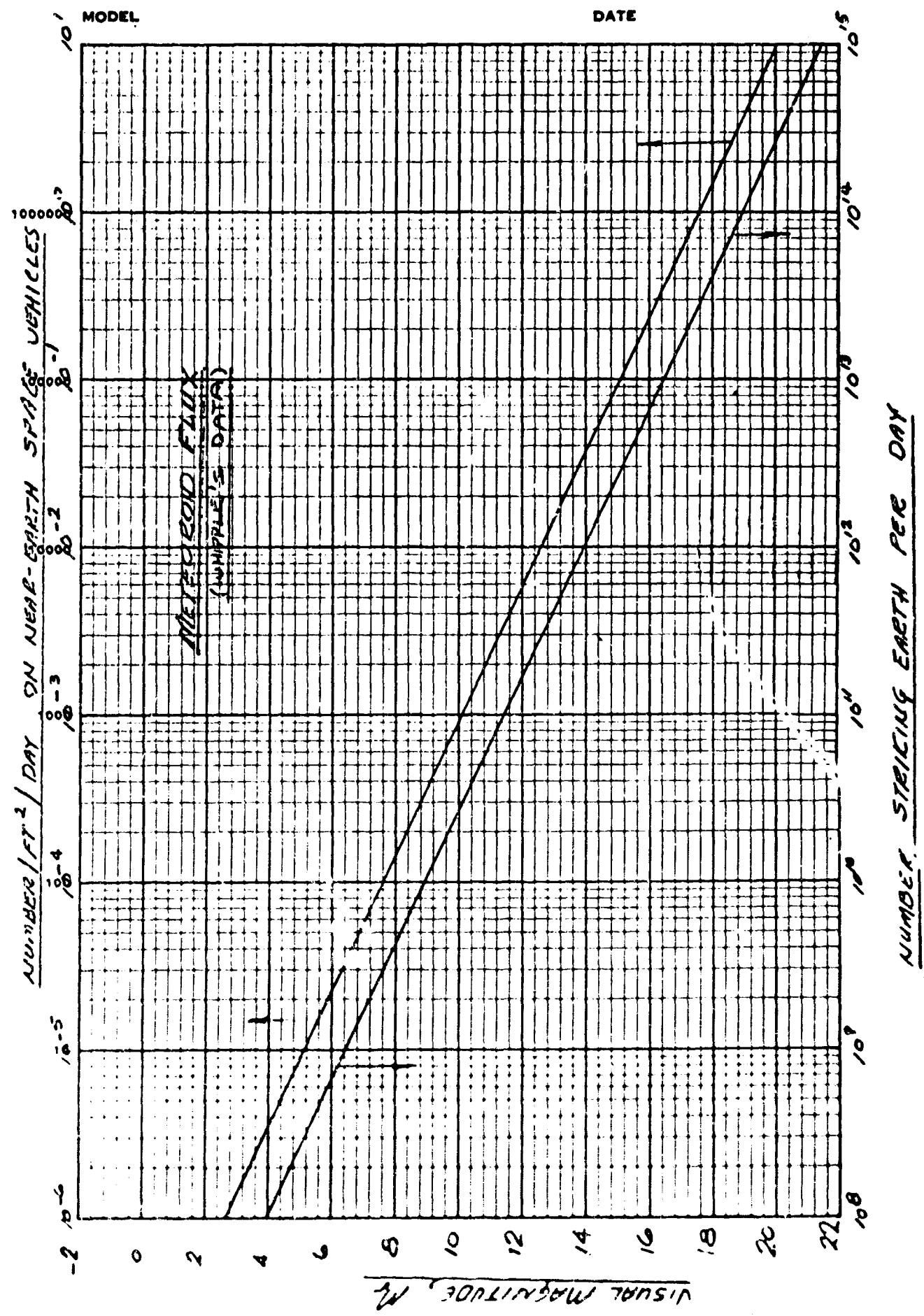
volume is proportional to the momentum of the projectile then the value of the exponent is only $\frac{1}{3}$. Calculations by R. L. Bjork, of Rand, indicate that the $\frac{1}{3}$ power should be used for high velocity collisions while the 2/3 power is to be used in the low velocity region.

Bjork's calculations lead to the following relation:

$$\frac{P}{d} = 1.169 \ v^{0.315} \tag{5}$$

A good estimation of the penetration of the skin of a space vehicle is that penetration occurs whenever P exceeds two thirds of the skin thickness.

(d) Surface Erosion. A mean velocity of 15 km/sec was taken by Whipple as that corresponding to minute meteoritic dust particles which tend to erode the vehicle's skin. The maximum mass eroded from a surface was given by Whipple as equal to 4.5×10^{-13} gm/cm^2/sec. For a surface density of 3 gm/cc this corresponds to 1.5×10^{-13} cm/sec. Erosion will also result from corpuscular radiation from the sun and from sublimation of the surface by the extended solar corona. Whipple estimates that erosion due to these three factors will destroy the optical properties of a surface after about one year.

(e) Hazard Evaluation. It is recommended that the following procedure be utilized in order to assess the nature of meteorite hazards:

(1) Use Whipple's data for determining the frequency of encounter of meteorites.

(2) Use Equation (5) and Bjork's estimates of the effects of meteoroid penetrations.

(3) Utilizing the above data and estimates, establish curves showing the relation between the number of meteorites and the sizes of punctures produced in different kinds of space vehicle surfaces as a function of time.

3. Atmospheric Composition and Density

Some pertinent characteristics of the upper atmosphere are summarized in the following table.

ATMOSPHERIC COMPOSITION AND DENSITY

Miles	Km.	Region	Composition	Pressure psi	Rel. Atmos. Density(SL=1)	
9	14			1.7		Press. Breathing and press. suit(or press. cabin) required.
10-12	15-20	Partially Space Equiv.	78% N_2 21% O_2		10^{-1}	Sealed, Pressurised Cabin required.
15	24	Ozone Layer; Max. Concn:	10 ppm O_3			.
19	30			0.16	10^{-2}	Max. intensity at 55° lat. of secondary radiation.
25	40					Heavy Primary Cosmic Radiation Absorption; UV and Solar Absorp.
30	50	Dynamic Weightlessness				Upper limit for Aerodynamic Lift and Navigation.
43	60-70	Ionosphere Begins		0.465×10^{-4}		Ballistics or Reaction Control required.
62	100			0.256×10^{-4}	10^{-6}	No sound transmission, no light scattering.
75	120					Lower limit for meteor absorption. Upper limit for Aerodynamic heating.
100	160	Molecular Dissociation	Atomic Oxygen			
120	200	Total Space		0.258×10^{-9}	10^{-11}	Effective Atmosphere Terminates.

B. Induced Environment

The induced environment factors are those which are created or modified by operation of the space vehicle system and its crew.

1. **Nuclear Radiation.** Radioactive isotopes or a nuclear reactor may supply energy for propulsion or for auxiliary power. Another possible source is a nuclear explosion set off at high altitudes or in space. Particle types, fluxes, and energies will vary with the source, separation distance, and time.

2. **Acceleration, Vibration, and Acoustic Noise.** There will be transient and steady state accelerations and vibrations during boost and re-entry. Vibrations may also be generated by equipment on board. Accelerations due to rotation may be introduced intentionally to establish an "artificial gravity", or may result from malfunction of altitude stabilizing equipment. Acoustic noise will be generated from various sources during all phases of operation.

3. **Partial or Zero Gravity.** In addition to physiological and psychological effects on the crew, partial or zero gravity is significant in structural design criteria and in aspects of equipment design and performance. Fluid behavior is affected in processes of heat transfer, phase separation in boiling and condensing, and in cabin atmosphere control.

4. **Cabin Atmosphere Contamination.** The human occupants contribute CO_2 and moisture, and trace dusts, aerosols, indole, skatole, hydrogen sulfide, methane, and bacteria to the cabin atmosphere. Equipment may contribute CO, acroleins, and various hydrocarbons. Control is required from both toxicity and odor considerations.

VI. HUMAN FACTORS

A. Crew Tasks

Crew tasks to be performed either within a re-entry type of vehicle, or within a space station will most profitably utilize man's unique capability to sense, discriminate, decide and take appropriate action. In comparison with unmanned vehicles or ground simulators, functions which can be performed by a space crew will permit more precise evaluation of space phenomena and physical and biological effects of space environment; and flexibility and reliability to the vehicle; and provide more realistic training and indoctrination for space exploration. The following list is by no means complete or comprehensive, but indicates some of the more obvious tasks to be planned for manned operations in space.

Scientific Observation

Studies of Earth's surface, atmospheric phenomena, (e.g., cartography, cloud cover, etc).

Astrophysical investigation and research.

Meteorological studies.

Biological effects of cosmic radiation, weightlessness, combined stresses.

Research studies in human and animal physiology, behavioral sciences.

Plant ecology.

Military Observation

Reconnaissance, surveillance and intelligence of military air-land-sea activity.

R&D, test and operation of electronic countermeasures (and ECCM), camouflage techniques, and other military arts.

Coordination of weapon systems.

Data collection and transmission of geodetic data.

Operation of relay stations for communication, logistic support.

Navigation, remote guidance.

Vehicle Control

Back-up to automatic controls (plotting course, position, attitude, velocity, time over landmarks).

Guidance and control in re-entry sequence

Orientation and alignment of vehicle

Control of oscillation rates

Monitoring or braking system

Maintenance and Repair

Detection, replacement and/or repair of malfunctioning units and systems.

Problem-solving of failures of units and systems.

Monitoring and Control of

Capsule Environment (pressure, composition, temperature, humidity, etc.)

Physiological Functions.

Integral radiation doses.

Socio-psychological, behavioral responses of crew members.

Testing of materials, new equipment, and instrumentation under loads, zero "G", etc.

Communication

Receive and transmit relay signals from satellites or other vehicles.

Data Collection, Organization, Evaluation, and Transmission

Physiological and Psychological responses (verbal and telemetered reports).

System status.

Mission status.

Training

Train, indoctrinate, check-out new crews and replacements.

Test training devices, rehearse emergency procedures (or other little used techniques) to maintain crew proficiency.

B. **Physiological Aspects**

Human metabolic requirements and tolerance limits to environmental changes are reasonably well defined for many of the normal and stress conditions which can be simulated in ground laboratories; for example artificial environments, acceleration and heat loads, noise and vibration, short periods of weightlessness. Obviously, human tolerance to prolonged weightlessness, prolonged exposure to primary cosmic radiation, possibly complete isolation without communication with ground station, can only be determined under actual space conditions with the vehicle crew serving either as passive observer or as a functioning part of the space-vehicle complex. A greater problem, with respect to physiological aspects, may be the synergistic action of a number of physical and psychological stresses imposed simultaneously. Some of the parameters which apply to design of life support systems and man's capability are presented as graphs reproduced from Congressional Document, 1959 - H.D. 86, "Space Handbook: Astronautics and its Applications" (G.P.O.). The compilation of physiological and biophysical data, gathered in first quarter of 1960 will be augmented or revised as more complete information becomes available.

1. _Food and Water Requirements_

The daily metabolic turnover for standard man weighing 154 lbs. (with respiratory quotient of 0.82) averages 2830 calories.* Food, water, and oxygen for maintaining metabolic balance requires, by weight:

80 gms Protein)

270 gms Carbohydrate)
150 gms Fat) $\qquad$ 14.59 % = 1.15 lbs./day

2200 gms H_2O $\qquad$ 61.37 % = 4.85
862 gms O_2 (603 liters) $\qquad$ = 1.9

Total   7.9 lbs/day

*H. G. Clamann, "The Engineered Environment of the Space Vehicle", Chap. 6, MAN IN SPACE, Duell, Sloan and Pearce, 1959.

The Ionics Report gives a total weight of almost twice this amount for optimum food, water and oxygen requirements. Figure 3 (adapted from graph given in Konecci's "Shielding & Nuclear Propulsion) indicates that for mission times longer than 2 to 3 weeks, when the cost in pounds for food, water and oxygen supplies becomes greater than re-cyling/regenerating system, water recyling and CO_2 regenerating systems must be considered for weight economy. For mission times greater than 100 days without resupply, a closed ecological system must be considered.

2. Atmosphere

The relationships of ambient pressures, atmospheric composition, and oxygen partial pressures are shown on Figure 4. CO_2 tolerance is given as function of exposure time in Figure 5. From a physiological standpoint, a normal or near normal sea level sealed cabin pressure is optimum for efficient functioning of the crew.

3. Radiation Tolerances

The recommended limit for accumulated occupational radiation dosage, in rem*, is determined by the formula $D = 5 (N-18)$ where N is the age in years. A more realistic dose limit for exposure to radiations in space should be based upon criteria different from those applying to an occupational population group assumed to be continuously exposed to an average 5 rem/yr over a 45-year period.

Acute doses of 50 rem or less should produce no detectable injury or immediate effects provided previous and subsequent accumulated dosages do not exceed the accepted MPD. However, acute dosages above 100 rem, superimposed upon other stresses of space flight, could have more serious effects upon an astronaut than might normally be expected after accidental or clinical radiation doses.

One of the most critical problems is the physiological effects, under space conditions, of ionizing radiation, particularly primary cosmic nuclei, against which shielding is impractical, if not impossible. A few of the factors which may affect criteria for crew selection and rotation are:

(a) Individual's age and previous radiation exposure history.

(b) Effectiveness of protection techniques such as close body shielding, biochemical prophylaxes, etc.

(c) Results of present and future radiobiological research.

Human tolerances to radiation are summarized in Figure 6.

4. Weightlessness

Prolonged exposures to 0 "g" or sub-"g" will be encountered

*rem = rad. x relative biological effectiveness factor
rad = 100 ergs absorbed per gram of tissue
Roentgen = 96 ergs absorbed per gram of tissue.

DAILY WEIGHT REQUIREMENTS FOR MAN'S VITAL NEEDS

(Oxygen, water, food)

Curve A: Normal Activity with H_2O re-cycling

Curve B: Normal Activity with H_2O re-cycling and CO_2 regeneration

Curve C: Normal Activity with completely balanced system (With allow for food-O_2 supply and CO_2 conversion)

TIME (days)
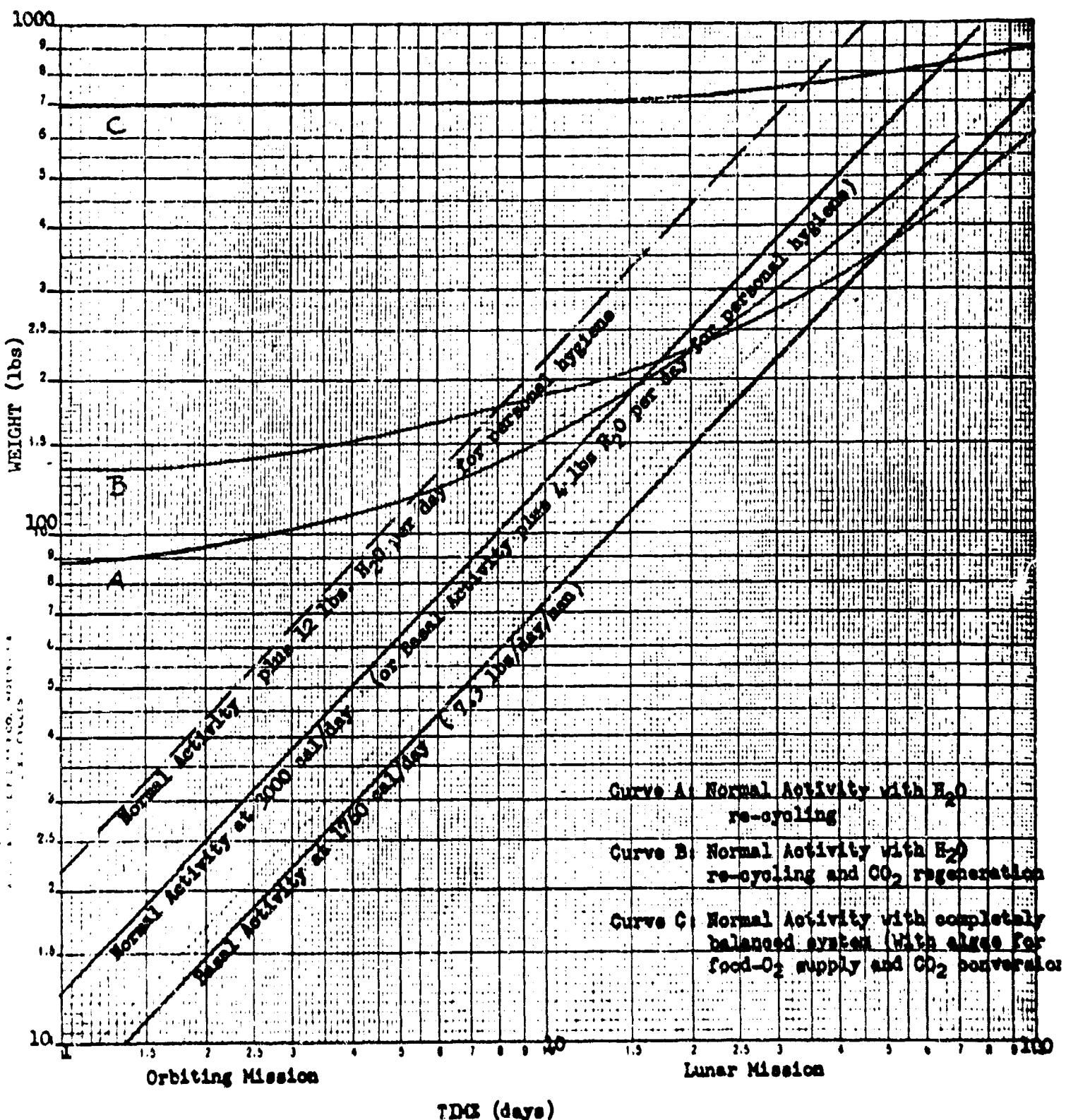
Figure

(Adapted from Trapp & Konecci,
Shielding and Nuclear Propulsion
Douglas Aircraft Report, July 1959)

—Human tolerances —atmospheric
composition and pressure

FIGURE 4

Human time – tolerance – carbon dioxide partial pressure

Note: Normal sea level partial pressure of CO_2 (inspired) = 0.21 mm of Hg = 0.03%

FIGURE 5

— Human tolerances to radiation
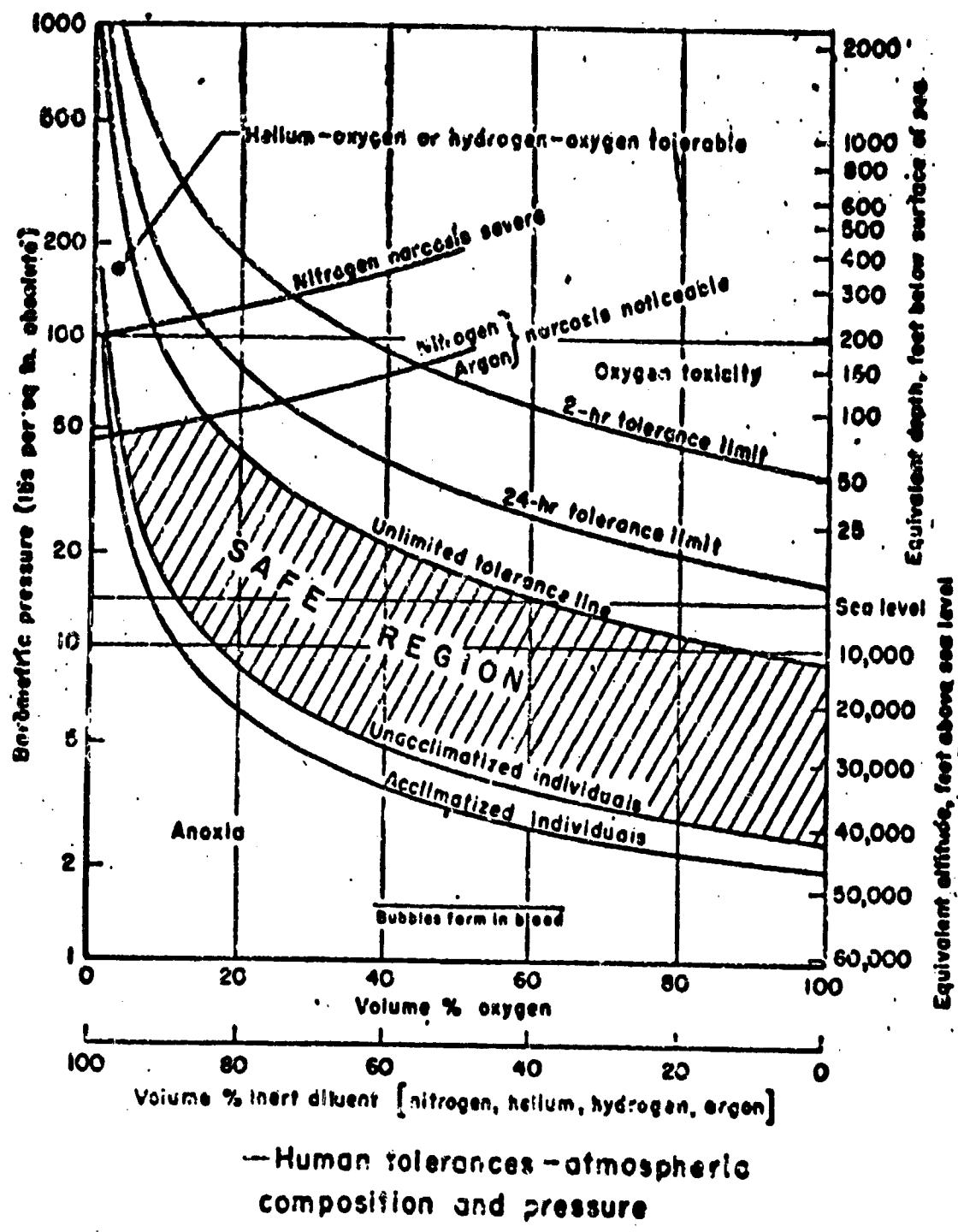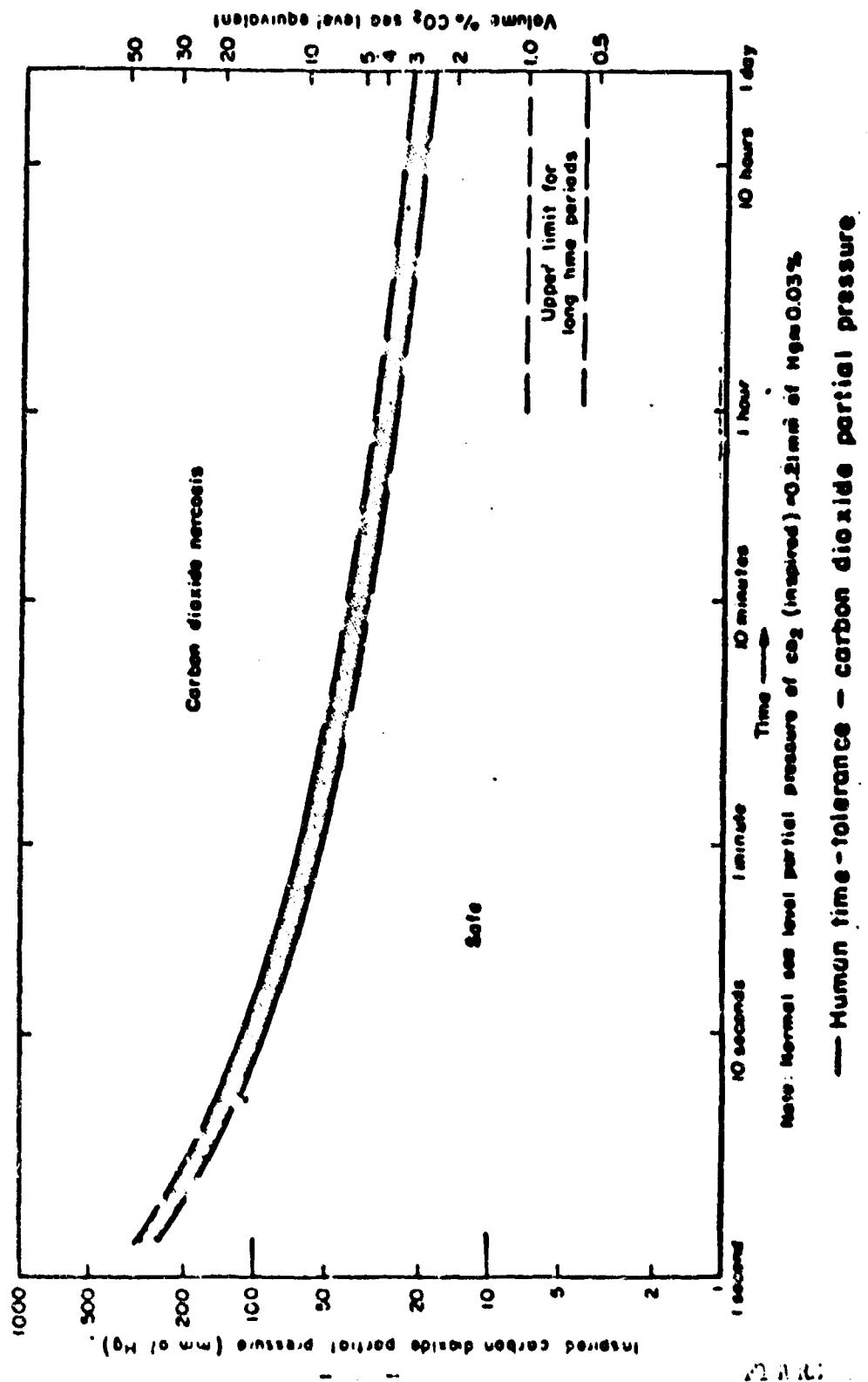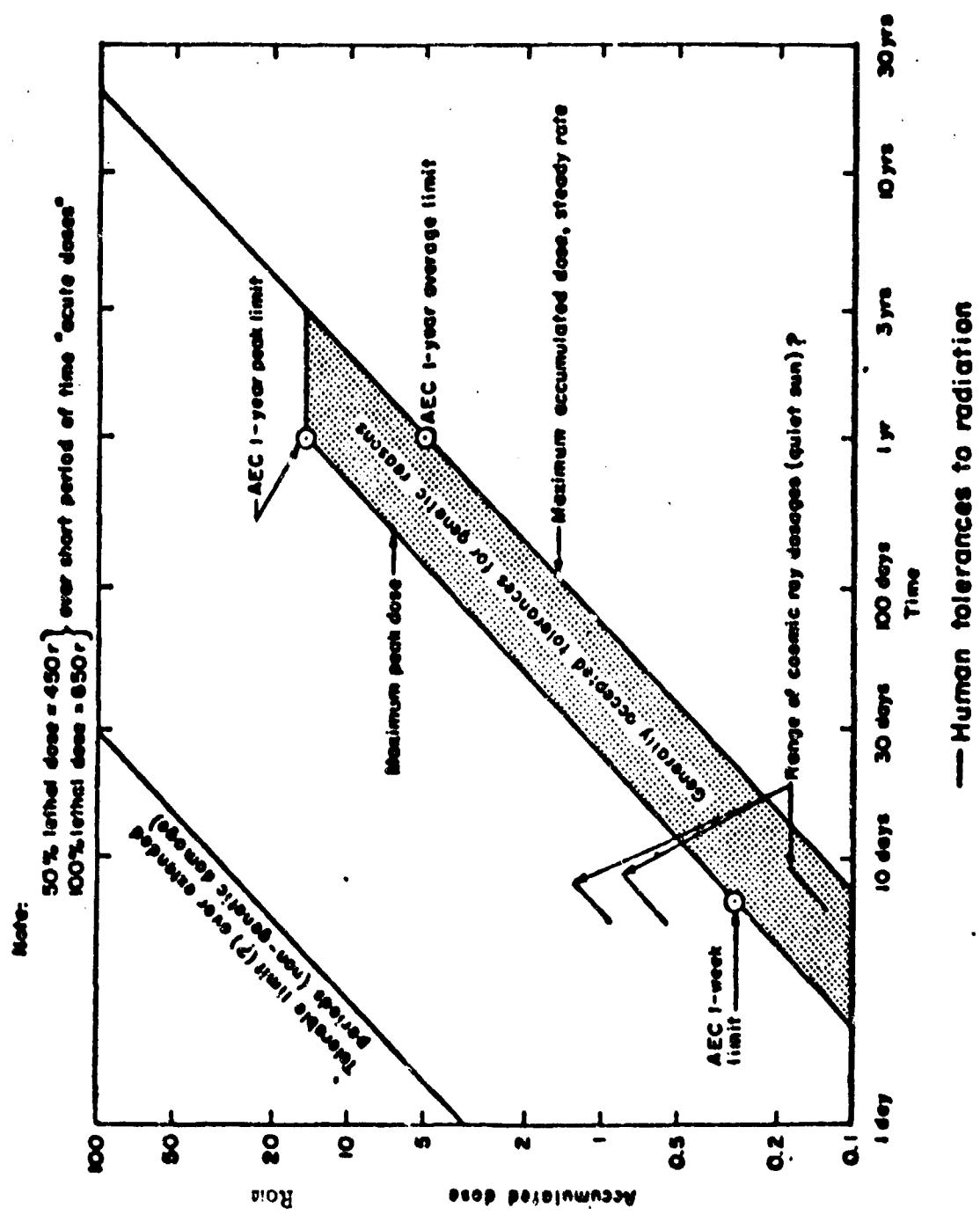
in orbital or deep space flights unless the vehicle is constantly undergoing either linear or angular acceleration. Energy reserves, engineering limitations, systems failures and human tolerance for complex angular acceleration may obviate the possiblity of simulating "g" by continued vehicle acceleration. It is, therefore, important to consider the probable consequences of both short and protracted exposures to near or absolute weightlessness in order to establish design guide lines for life support systems and personal equipment to attenuate any adverse responses that are anticipated.

In order to define these probable adverse responses a comprehensive review of human physiology is required to determine the physical, physiological and metabolic functions that are significantly influenced by gravitational forces and would, therefore, be altered when such forces were markedly reduced. Prediction of probable patterns of, and requirements for adaptation of the man in this altered environment, can then be made, as well as the manner in which such adaptations will create special design requirements in the vehicle. Of as great an importance will be consideration of how the alteration in functions induced by exposure to sub-gravity states will affect tolerance for exposure to normal or hyper-gravity states during return to earth or other planets.

(a) Discussion

Abundant clinical evidence is available to indicate that musculo-skeletal structures develop strength and substance to a degree which correlates with the magnitude of stress developed in the structure of concern. For example, large, well developed muscles result from often repeated stressing of the muscles, heart enlargement results when the work done by the heart is increased by pumping against an increased blood pressure. Bone structure increases its strength and density when exposed to stress and the rate of healing of bone fractures is increased by static stress. Opposite effects result when muscle or bone are not working and loss of substances or "disuse atrophy" and decreased strength develop in a matter of a very few weeks in muscle and bone structures immobilized in casts or splints. In a normal gravitational field musculo-skeletal structures consistently work against the pull of gravity and also against the resistances to frictional and elastic forces developed in and between the moving tissues of the body. In a near 0- "g" field the work done in performing motor functions would be greatly reduced and without some additional enforced conditioning program some "disuse atrophy" would soon be apparent. Both physical and chemical changes would result, as well as decreasing ability to tolerate "g" stresses encountered during re-entry conditions. Also the normal hydrostatic pressures developed in the blood and other body fluid columns in a normal 1- "g" environment would disappear in an 0- "g" environment. Normally a rise of diastolic blood pressure and an increase in heart rate occurs when a person changes position from a supine to a sitting or standing attitude; this compensates for the effects of gravity upon circulation.

Likewise, selective constriction of certain blood vessels and dilation of others takes place at such times to regulate the the flow of blood when various body areas are subjected to different hydrostatic pressures. Pressure receptors and chemo receptors, in various arteries of the body, are stimulated by pressure and circulatory changes to help effect the adaptation described above. The ability of these structures and the muscular layers of the vascular walls to rapidly adapt to these changing conditions is quickly lost even in healthy persons maintained at bed-rest where changes in hydrostatic pressures are essentially absent. Consequently, a sudden change in position from supine to erect, after a few weeks of bed-rest, results in the failure of circulatory adaptation and causes sudden loss of consciousness. Prolonged exposure to O- or sub "g" could be expected to have affects similar to prolonged bed-rest, and the subject suddenly exposed to an increased gravity state would be vulnerable to such impaired responses.

The energy requirements of the body will correlate with the amount of work performed, so would be expected to decrease in a sub-gravity field unless enforced work was planned to compensate this difference.

Likewise, oxygen utilization, respiratory function and carbon dioxide production would change in accordance to altered energy output. These in turn would affect design consideration for food and oxygen supply, carbon dioxide absorbers, thermal control, etc.

Body size and shape will be altered by removal of gravity forces, which in turn could affect design of personal equipment.

Voluntary and reflex motion would be exaggerated in an "O" gravity field until antagonistic muscle groups had undergone adaptation. Upon return to normal or high "g" states disbalance between antagonistic muscle groups would be apparent.

Visual function would be altered by a reduced gravity field with a reported apparent upward displacement of objects.

Locomotion and stability would be seriously compromised by absence of friction between the body and the vehicle structure. Orienta-tion would be compromised by loss of otolith position sense and proprioceptive sense. The sleeping subject would likewise be without visual orientation. Disorientation and reflex autonomic and psychic disturbances have been demonstrated to occur in subjects awakened while in an O- "g" state during a parabolic flight in aircraft.

Ingestion of food and fluid and probably digestion and elimination will be affected by an altered "g" state. Changes in body chemistry, loss of mineral salts, etc., would be expected to accompany "disuse atrophy", and altered circulation if artificial means to maintain normal function were not planned.

A complete study would greatly expand the list of changes, and could point out many areas of design, indoctrination, and training that would be most important in aiding and measuring adaptation to reduced "g" states. The following abbreviated lists divide anticipated changes in man exposed to sub or 0- "g" states, into acute or short termed effects, and chronic or long term effects. Also a few of the probable serious results of abrupt return to a normal or high "g" field of a subject adapted to 0- "g" will be listed. These lists assume that no techniques are employed to offset adverse effects of sub-gravity states and thereby help clarify problem areas where use of attenuating techniques or devices should be considered.

(b) Acute Weightlessness Syndrome

General

Slight increase in height and slight alteration of body shape.

Exaggerated motion with application of normal muscle forces.

Eyes and Vision

Disturbed flow of lubricating fluids of eyes with probable increased blink frequency.

Transient extraocular muscle imbalance.

Upward displacement of viewed objects (oculo-agravic illusion).

Ears

Absence of otolith function of static position sense.

Probable altered acuity for sensing angular acceleration.

Nose and Sinuses

Altered drainage of sinus cavities.

Tendency for displacement of food and fluid from mouth into nasal passages.

Mouth and Throat

Impaired deglutition.

Chest and Lungs

Decreased relaxed chest volume.

Possible altered cardiac axis due to upward displacement of abdominal viscera.

Exaggerated diaphragmatic excursion during respiratory cycle.

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Increased blood flow toward lungs for a given venus blood pressure.

Altered pattern of circulation through lungs.

Probable reflex changes in respiratory rate.

Heart

Increased volume flow for same energy output of heart.

Probable reflex changes in heart rate.

Gastrointestinal

Increased mobility of viscera with normal strength of peristaltic contractions.

Possible reflex nausea and vomiting as a result of disturbed vestibular function.

Skeletal Muscle and Peripheral Nerves

Impaired locomotion.

Exaggerated responses.

Impaired task performance.

Loss of proprioceptive sense.

Impaired postural sense.

Psychiatric

Possible falling sensation.

Euphoria.

Anxiety.

Disorientation.

Hunger for stimuli.

(c) ### Chronic Weightlessness

General

Some increase in body height.

Some alteration in body shape.

Eyes and Vision

Disturbed flow of eye secretions.

Probable increased frequency of blink reflex.

Adapted extraocular muscle balance.

Oculo-agravic illusions.

Ears

Absence of otolith function of static position sense.

Probable altered acuity for angular acceleration.

Chest and Lungs

Decreased relaxed chest volume

Possible altered cardiac axis due to upward displacement of abdominal viscera.

Adapted respiratory excursion.

Adapted pulmonary blood flow.

Adapted reduction in respiratory rate with weakening of respiratory muscles.

Heart and Blood Vessels

Probable reduction of blood pressure.

Probable cardia atrophy.

Decreased cardiac reserve.

Decreased muscular tonus of blood vessels and impaired reflex adaptation to changing of hydrostatic pressures.

Gastrointestinal

Adapted peristalsis.

Possible reflex nausea and vomiting with episodes of disorientation.

Skeletal Muscle and Peripheral Nerves

Muscular atrophy and reduced strength.

Adapted locomotion and other motor performance.

Adaptation to absence of proprioceptive and postural sense.

Bone

Possible osteoporosis due to "disuse atrophy".

Psychiatric

Adaptation to zero "g" state.

Body Composition

Probable lowered total body supply of bone salts, electrolytes, protein, and blood and fluid volume.

(d) ### Probable Serious Results of Abrupt Exposure of a Weightlessness-Adapted Subject to a High "G" Field

Eyes

Extraocular muscle imbalance.

Ears

Sudden return of sensation of position sense with possible disorientation effects.

Chest and Lungs

Increased work to perform respiratory excursion.

Sluggish diaphragmatic motion.

Altered blood flow through lungs.

Heart and Blood Vessels

Impaired cardiac reserve and impaired neurocirculatory regulation of blood flow in the presence of increased hydrostatic pressures.

Possible decompensation and syncope.

Skeletal Muscle and Peripheral Nerves

Reduced muscular strength to resist gravity.

Return of proprioceptive and postural sense.

Alteration of body posture and alteration of locomotion.

Bone

Impaired structural integrity of bone with predisposition for fractures induced by high "g" forces.

Psychiatric

Altered responses to sudden increase in number and types of stimuli reaching the central nervous system.

(e) Remarks

The above partial listing of probable effects of weightlessness discloses several requirements for men who may be exposed to this condition for protracted periods of time. For example:

Laboratory facilities should be considered to measure daily protein, fluid, electrolyte and mineral losses, etc., so a work-exercise and dietary regime could be enforced to maintain normal metabolic patterns and preserve normal tolerances for "g" and other stresses.

Effects of the probable changes in body size and shape must be considered in design of personal equipment. Consideration should be given to mechanical devices which can easily be designed to affect differential pressures in various body parts to stimulate and exercise reflex cardiovascular adaptive mechanisms which normally compensate for similar changes induced by gravity.

Enforced exercise can be performed on energy-storing machines to simultaneously condition the men and create electrical or pressure energies for use in the vehicle system.

Techniques to aid processes of eating, drinking and waste-product elimination can be determined. Aids to stability and locomotion of the man can be designed into the vehicle structure.

The absence of normal convection of environmental gases in a state of 0 "g" would introduce the hazard of rebreathing high concentrations of CO_2 which could collect about the face area of a subject if forced convection were not employed. During sleep, when the face may be, to some extent, pocketed by bed clothes, etc., special consideration of adequate forced circulation across the face area would be indicated.

A comprehensive study of the probable effects of weightlessness should define numerous areas where integrated man-machine life support system design would be influenced.

5. Acceleration Tolerance

Accelerations produced in launch and re-entry are expected to be within the human tolerances shown on Figure 7. Several techniques for increasing tolerance have been, or are currently, under study by a number of military and civilian agencies. One technique, designed and tested by Convair, which is the use of positive pressure breathing to increase tolerance (reported in ZM-AM-001, Jan. 1959) is now being intensively studied by Service agencies. It is not anticipated that acceleration forces will be a critical problem for low-orbital missions.

6. Acoustical Noise and Vibration

Noise level thresholds sufficient to produce temporary or permanent hearing loss vary from about 100 db to 125 db depending upon frequency
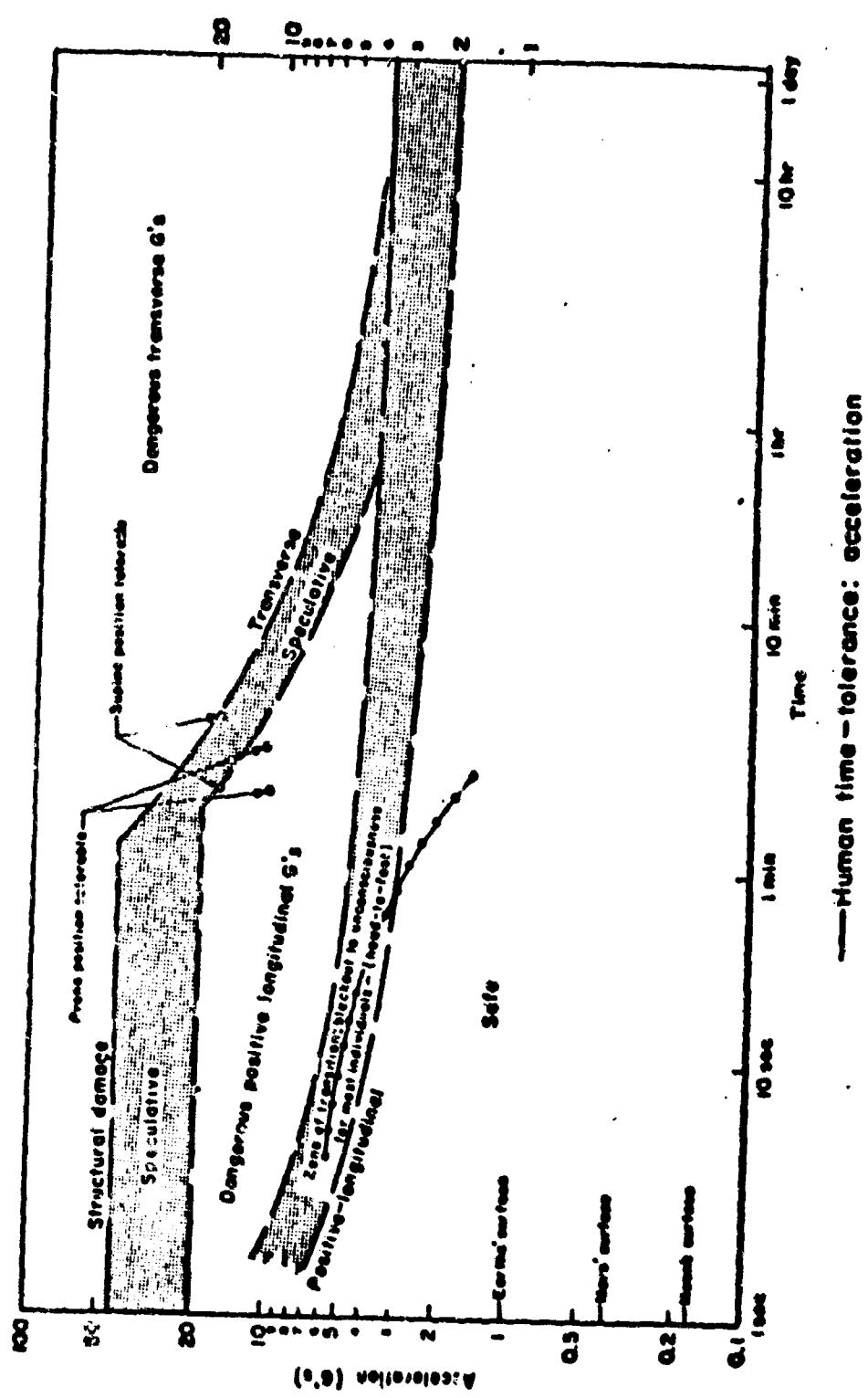
FIGURE 1

- 1 -

and duration. Protection against sound levels during rocket propulsion stages or engine malfunction should be no major problem when acoustical materials and/or ear defenders are used. Noise levels produced by equipment operation or other sources though well below the threshold for permanent hearing loss, may be a critical problem if noise intensity causes serious interruptions in communications.

Within the frequency range of greatest sensitivity of the human ear, noise intensities have in general the following effects:

140 db	produces pain
80 - 120 db	noticeably uncomfortable - causes fatigue and irritability.
50 - 80 db	comfortable hearing
20 - 50 db	too soft for easy hearing

More complete tables of acoustical noise levels over wider frequency bands are given in a number of reports.

Vibration

Vibration of low frequency - high amplitude produce greater discomfort (e.g. motion sickness) than vibrations of higher frequency-low amplitude. Low levels of tolerance to sinusoidal vibrations range from 1 to 2 g at 3, 4, 7, and 8 cps, to as high as 7 to 8 g at 15 cps. Some problem areas may exist in providing damping to reduce physiological effects of vibration and oscillations.

7. **Decompression**

Biological effects of gradual decompression are: 1) hypoxia from loss of oxygen partial pressure and 2) decompression sickness from loss of total cabin pressure. Tolerance levels bear a complex relationship to partial pressure ratios, rate of pressure change, and type of diluent gas. These relationships are discussed in the referenced reports.

Time tolerances within a range of oxygen partial pressure values are shown on Figure 8. Lowest safe limits, as given in the literature, lie between 90 and 100 mm Hg. Evidence of performance deteriorations at pp O_2 below 115 mm Hg and appearance of psychological effects at 96 mm Hg have been reported (ref. Ionics Report). Symptoms of acute hypoxia (sleepiness, lassitude, altered respiration, inability to perform tasks, loss of consciousness and death) first appear at pp O_2 of 80 mm Hg and are fully developed at 60 mm Hg.

Symptoms of decompression sickness (pain, "bends", chokes, etc.) due to nitrogen and other body gases evolved and trapped as bubbles in body tissues - can appear within 15 - 20 min. when total barometric pressures reach 6 to 8 psi at $O_2 \cdot N_2$ ratios of 21%: 78%; pre-breathing 100% O_2 for 2 hours at normal barometric pressures reduces incidence of symptoms when total pressure is reduced below - 5.5 psi.
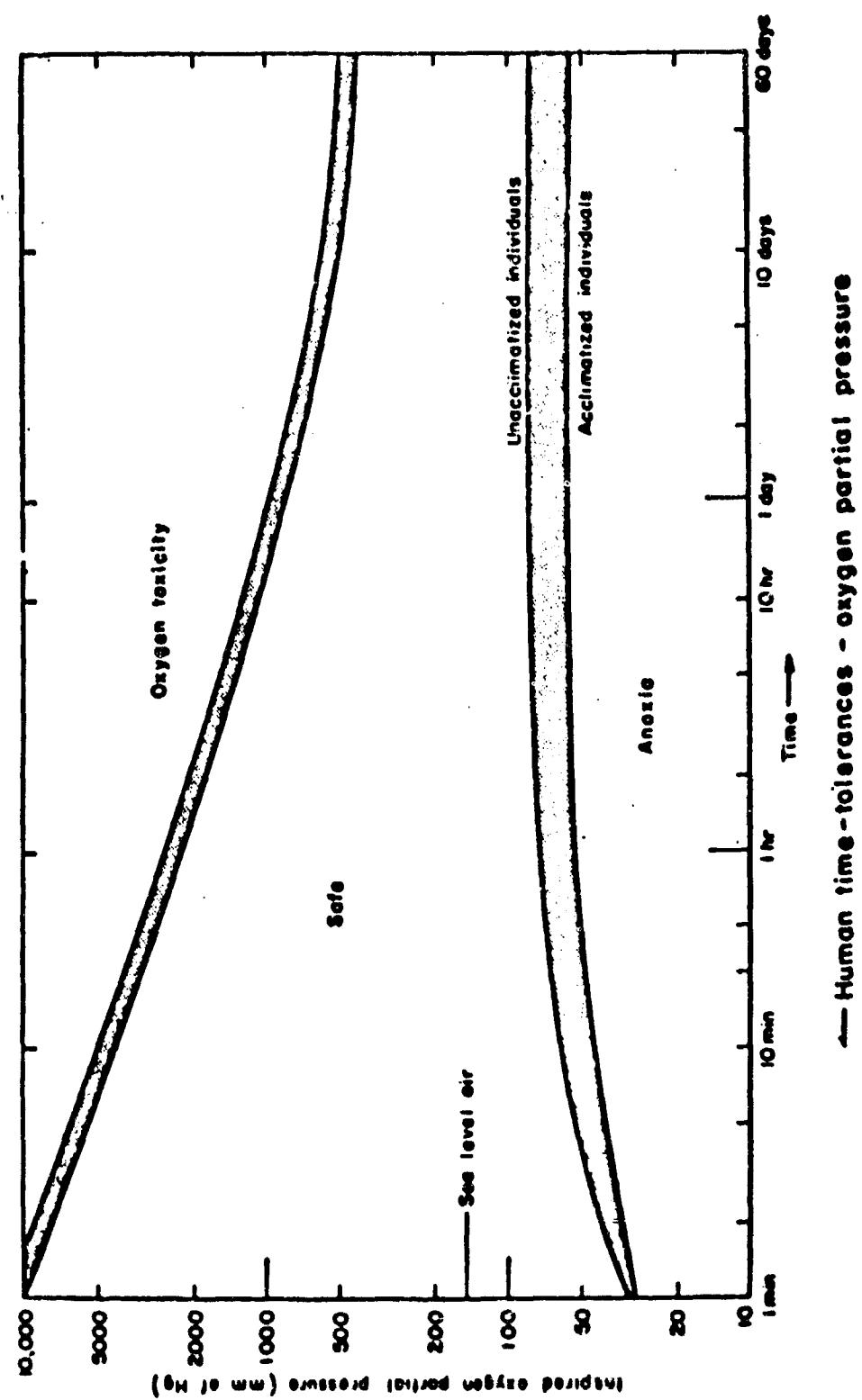
— Human time–tolerances – oxygen partial pressure

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During altitude chamber tests, rapid decompression from about 11 psi to 6-1/2 psi has resulted in loss of consciousness, paralysis, and injury to lung tissues. Complete recovery was effected by gradual re-compression. The probability of rapid or explosive compression (with fatal results) is considerably reduced by the hermetic sealing of compartments, structural techniques, and other safety measures. Konecci* has calculated that it would require a hole about 50 sq. in. to decompress a 200-cu. ft. cabin to less than 2 psi in 1 sec. Therefore, gradual decompression with its hypoxic effects are considered to be the more serious hazard.

8. Temperature Tolerance

The effects of relative humidity and duration of exposure to various temperatures are indicated on Figures 9 and 10. Man can function most efficiently at temperatures between 60° and 80°F, at relative humidity below 70% and above 30%. Protective clothing is required beyond these limits of temperature. Optimum temperature is considered to be 70°F at 50% RH. With protective clothing (and for short exposure times), temperature tolerance limits are considerably extended although tests conducted at Convair (as reported in ZR 658-051) have shown that: 1) physiological mobilization to changes in temperature from 100° - 150°F is greatly in excess of physical stress, 2) psychological effects of unexpected equipment failures greatly increase the stress response and 3) human perception of temperature changes is much less acute below about 70°F and above 150°F.

9. Wastes

The handling and disposal of biological wastes is essentially an engineering problem in design of life support systems. Those aspects of hygiene and sanitation which are directly or indirectly related to waste product control are considered under the general topic of waste:

    1. Pathogenic organisms

    2. Odor

    3. Atmospheric toxins

    4. Dusts and aerosols

Pathogenic organisms (such as respiratory infections) can be introduced into the closed cabin environment before launch and during checkout by infected ground personnel or even carried by crew members who may have been exposed to viruses, or other organisms. One function of the ground holding facility will be the pre-launch isolation and careful medical supervision of space vehicle crew, as well as ground

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*Konecci, E. B., "Hazards of Sealed Cabins". Astronautics, Feb. 1959.

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—Approximate human time—tolerances: temperature
Optimum clothing

FIGURE 9

Note:
Dependent also on activity, clothing, humidity, acclimatization, bodyweight, etc.
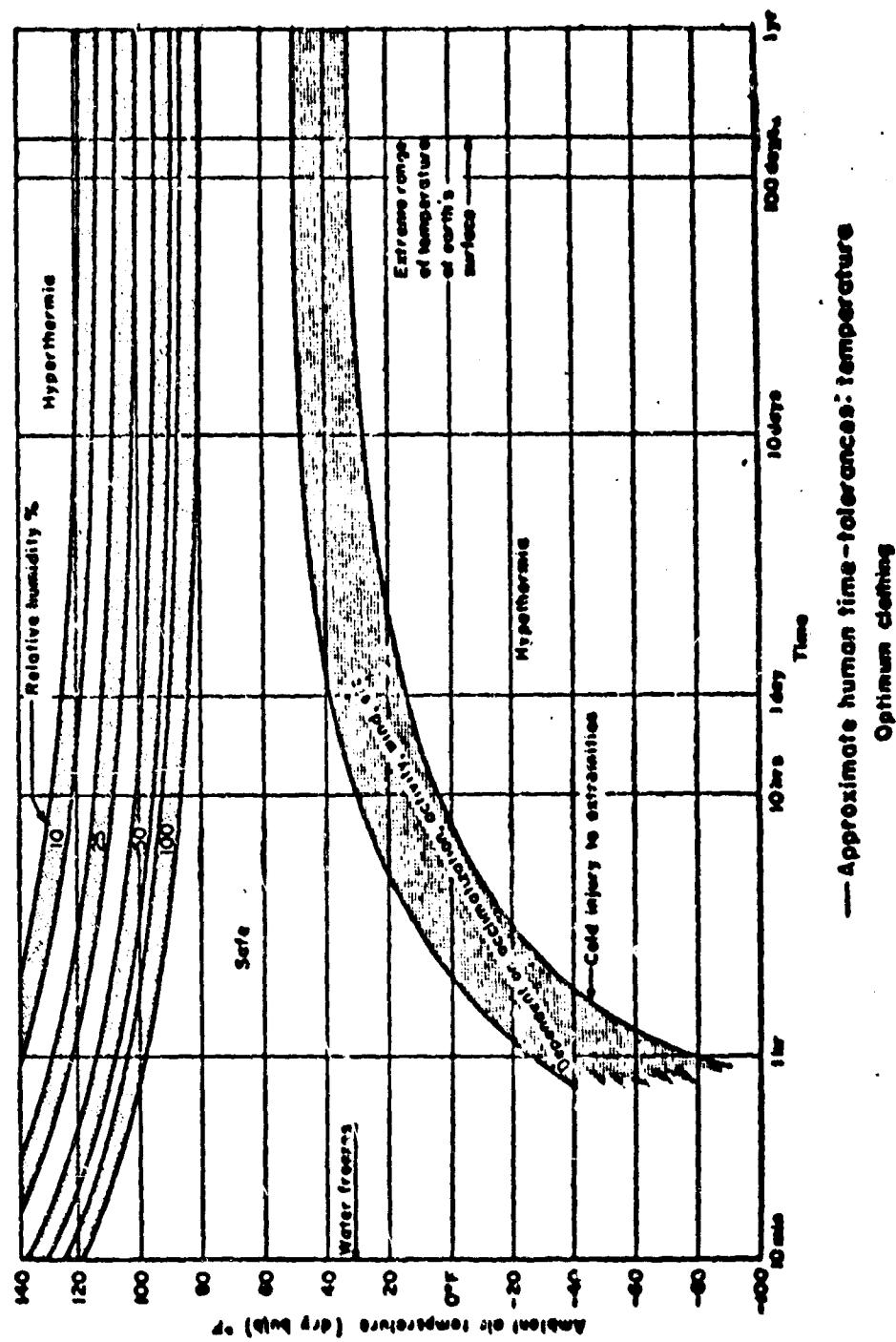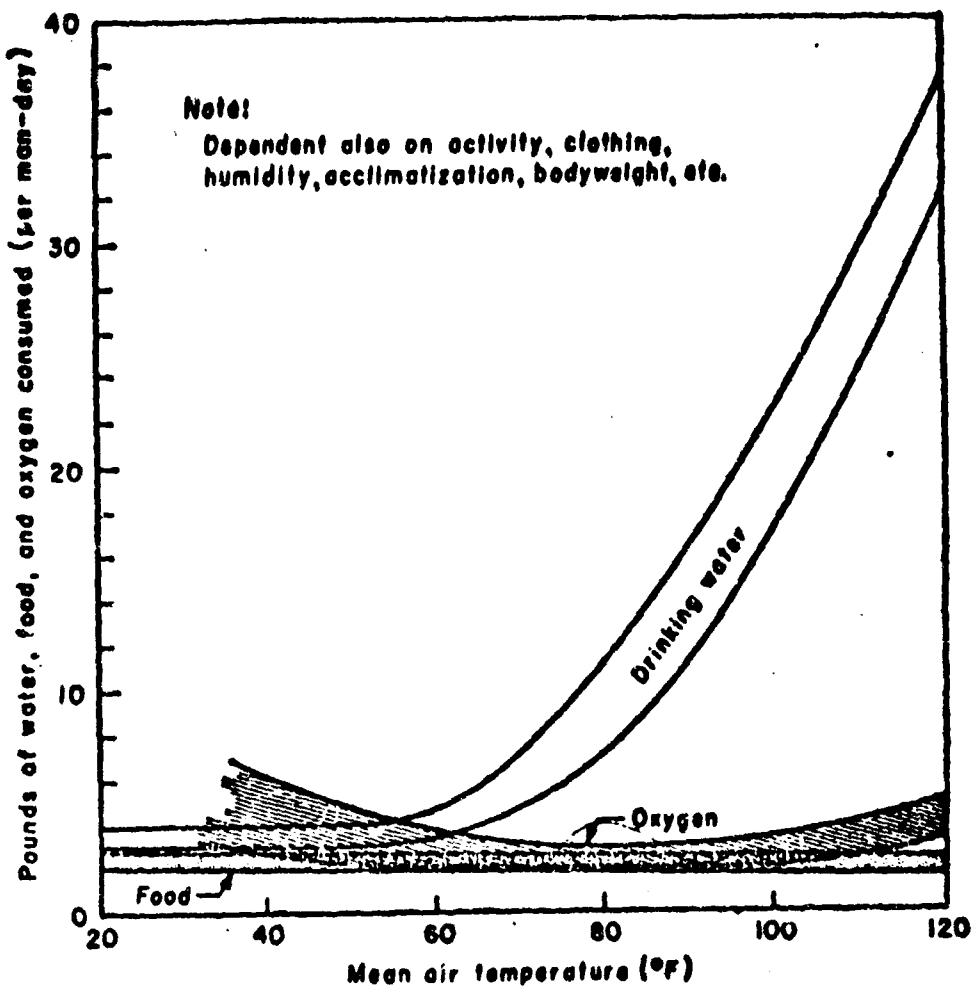
—Effect of temperature on water, food, and oxygen requirements

crew members. Effective sanitation control of cabin facilities,
equipment and supplies, and packaging and handling of foods and
liquids, will require techniques including rigid inspection, use
of disinfectants, and possibly, even sterilization before hermetic
sealing of compartments. In-flight control of dusts, aerosols, odors
will be provided by circulation-filtering-absorbent systems specified
in design of environmental control equipment.

Equipment and techniques in monitoring, collection, or sanitizing
methods, may be developed from reliable sensing apparatus for particle
size and toxic levels, the feasibility and effectiveness of air-
ionization devices; ultraviolet light. Submarine experience with
closed systems can be used as a basis for further investigation concern-
ing identification, build-up rates, and control of irritants and
toxicants, which may be released in equipment operation.

Maximum permissible concentration of aerosols, dusts, odors, and
toxic materials for a wide spectrum of chemical compounds are given
in Industrial Hygiene Handbooks, and other references listed in
bibliography.

C. Psychological Aspects

A comprehensive study of psychological problems of manned space flight
has been reported by Icnics for CV Astronautics. Some of the psychological
factors discussed have direct relationship to design of life support
systems. In an analysis of crew size in relation to effective performance
on space vehicle tasks, the maximum time periods given in the table below
are for a crew completely isolated in space without frequent communication
with ground stations (or other space vehicles), and without assurance of
emergency assistance. When the system is "opened" by a high degree of
vehicle reliability, dependable communication, and emergency help, the
duration of the mission will be considerably longer for a given crew size.

1.

Crew Size	Complete Isolated System	Open System	Conditions
one-man	1 wk.		Isolation limiting factor. Automation required Longer if carefully selected and trained.
2-man	10-15 days	15 wks.	If continuous monitoring tasks are not required.
3-man	30 days		Sociological problems leading to performance deterioration.
4-man	60-90 days		Smallest effective crew. Sociological problems reduced.
6-man	60-90 days		Group conflicts arise
12-man	90-120 days		If ideal selection & leadership.

-- 3. --

2.   The effects of isolation confinement and deprivation of stimuli are expected to be manifest in performance deterioration and sociological problems. Those recommended procedures which appear to have the most value in reducing these psychological stresses include the following:

    (a) Providing communications media such as radio, facsimile news, tape recordings

    (b) Providing recreational facilities such as television, movies, music, exercise

    (c) Providing meaningful tasks and rotation of duties.

3.   Optimum duty cycles, suggested in Ionics report are based upon an 18 hour day, with on-off-duty ratios of 3:6. Estimates of time required for most effective performance of critical tasks are given as 30 to 90 minutes and monitoring 60 to 180 minutes at one stretch without relief.

4.   Other recommendations such as peer ratings by individual crew members, the type of stimuli to be provided, and criteria for crew selections, are open to question.

5.   It is apparent that psychological stresses anticipated and the means of reducing them are matters of wider divergence of opinion than is the case with physiological aspects. Many of the solutions will be derived only from experience gained from early space missions.

D. Ground Support: Holding Facility

"Just as the ground-support equipment of the ballistic missile differs significantly from that of conventional aircraft, so must the support facility for the space-crewman of the future — the space crew holding facility — differ from present air crew support".[*]

The objectives of a ground-based space crew holding and support facility are to perform capsule assembly and checkout, perform final training and medical maintenance of the crewmen, and make a final selection of operators for a given mission from the crewman pool.

In keeping with Convair's long-range plans to become active in GSE and A&E programs, the holding facility requirements assume a position of double importance with respect to the present REA-supported program. First, the holding facility functions are as necessary to the eventual success of manned space missions as the on-board life support equipment and secondly, the holding facility sub-system buildings and equipments will constitute a substantial portion of the total GS requirements for a given base. Functional requirements for the space crew holding facility are in the earliest stage of assessment and evaluation; however, a partial listing of those requirements as presently conceived are as follows:

* Ref. Astronautics/Feb. 1960 Pins. B. "Holding Facility", p.40.

1. Space crew and support personnel quarters.

2. Insure prolonged operation capability.

3. Conduct life-support equipment modification.

4. Provide crewmen physical conditioning facility.

5. Provide preventative medicine and health maintenance.

6. Conduct crew-capsule integration and training.

7. Provide near-space simulation.

8. Conduct specific-mission final psychiatric-physical screening and selection.

The steps involved in the design of a holding and final training-environment facility are as logical and as systems-oriented as the design of the vehicle and its ground support equipment, and permit no great margin of error.

VII. ENVIRONMENTAL PROTECTION

A. Thermal Control Systems

The internal temperatures of the spacecraft under consideration are controlled by two major factors:

The first is the temperature of the outer skin of the space vehicle which depends either on aerodynamic heating during boost and re-entry or on the radiative transfer between the vehicle and its environment characterized by the Sun, the Moon, the Earth and space, when the vehicle is above the Earth's atmosphere.

The second factor is the heat generating characteristics of the personnel and equipment inside the vehicle, and the transfer of this heat to the vehicle either by radiation, convection or conduction. The outer skin temperature for a given vehicle configuration, orientation and trajectory can be controlled to a certain extent by the proper choice of the thermal properties of the surface materials.

The temperature variation of enclosed vehicle space will require the utilization of a thermal control system to provide the desired amount of heating and cooling for both the personnel and the equipment. The heating and cooling systems will be classified as either passive or active. A passive system is one which does not require the use of a heat pump. It might, however, utilize a fluid transport system and/or some kind of space radiators. An active system will be defined as one which uses a heat pump such as a mechanical refrigerator or a thermoelectric cooler.

1. Prediction of the Heat Loads

The prediction of the heating and cooling loads of a space vehicle depends on three independent factors:

(a) Aerodynamic Heating during Boost and Re-entry Phases. A space vehicle is structurally designed with a premium on saving weight since a 100 to 1000 pounds of booster are required per pound of payload. Thus it is a challenging problem to design vehicles to withstand aerodynamic heating. The effects of this heating will dictate both the external configuration and the external structural materials to be used.

Once the vehicle is designed, its outerskin temperature profiles during the boost and re-entry phases will constitute design parameters for the life support systems.

An existing Thermodynamics Group IBM 704 Program utilizing the reference enthalpy method has been in operation since 1958. This program is being utilized to calculate the outer skin temperature profiles of vehicles due to aerodynamic heating. It has shown good correlation with test data. However, it needs continuous updating to keep up with data of the properties of the upper atmosphere which are being accumulated from the latest satellite information.

(b) <u>External Radiative Heat Transfer.</u> The external sources of thermal radiation include the Sun, the Earth and the Moon as radiators, and the Earth's cloud cover and atmosphere as reflectors and scatterers of solar radiation. The trajectory, configuration, thermal conductivity, heat capacity and radiation absorptivity characteristics are the dominant object parameters in external thermal radiative heat transfer.

(c) <u>Internally Generated Heat Loads.</u> The internal heat loads include all the heat generated by the personnel and the equipment carried on board.

2. <u>Heating and Cooling Systems</u>

(a) <u>Passive Systems.</u> Passive systems are those which utilize the cyclic changes in radiative heating and cooling of an orbiting space vehicle to produce moderate temperatures in the living space.

Passive systems will either employ static components only or go as far as utilizing a fan or a blower to transport a fluid. They will, thus, possess an inherently high degree of reliability. The desirability of using a passive system instead of an active system cannot be over-emphasized. Further studies for the optimization of generalized passive systems should be earnestly pursued. The limiting areas to which a passive system can be used should be defined.

The techniques employed in passive system include the following:

(1) Radiation fins: These fins are used to radiate excessive heat to space.

(2) Variable thermal properties of outer skin: The thermal properties of the outer skin of the vehicle can be varied such that the relation between their solar absorptivity and their longwave reflectivity results in obtaining optimum internal cabin temperatures. In order to accomplish this, different material coatings may be used and a striped or patterned vehicle may result. Care should be taken in designing these coatings such that no cold or hot spots are produced.

(3) Conduction paths: This is a passive technique utilized to control the heat transfer through the use of various insulating and conducting materials.

(4) Variable radiation shields: This method utilizes some kind of windows or shutters to give the effect of variable radiation shielding, and thus control the amount of radiative transfer.

(5) Variable insulation: This technique utilizes the vehicle skin as a space radiator in conjunction with a heat transport fluid. The cyclic orbital heat load profile is used in order to arrive at an acceptable internal cabin temperature.

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(6) Radiators: Th   echnique employs a closed loop radiation
system, composed of a heat exchanger, a heat transport method
and a space radiator.

(b) <u>Active Cooling Systems</u>. The main advantage of an active system lies
in the attainment of higher radiator temperatures. Thus, higher heat
loads can be dissipated and a greater degree of control can be
achieved. Active systems will be divided into two categories:

(1) Mechanical Refrigeration Systems: These systems are either
open cycle or closed cycle systems. Open cycle systems
utilize expendable fluids and offer attractive opportunities
for integration with other vehicle subsystems such as auxiliary
power system, attitude control and water distillation. The
adaptability of water boilers to space vehicles is very promising.
The extension of previous Thermodynamics Group work on water
boilers to this application can be very fruitful. Operation in
zero gravity is one of the main problem areas here. Closed cycle
types include vapor compression and air cycles.

(2) Thermoelectric Systems: Thermoelectric cooling systems using
certain semi-conductors and utilizing the Peltier effect offer
considerable promise as refrigerators in the next few years.
They possess many advantages such as compactness and accessi-
bility to isolated areas which make them exceptionally attractive
for use in spacecraft.

B. <u>Radiation Protection</u>

1. <u>Shielding</u>

Crew protection against high-intensity protons in the inner Van Allen Belt
and in solar plasma fields is a major problem in vehicle design and shield-
ing. Exposure to Van Allen protons may be of short duration or avoided
completely. Solar proton storms encountered by a vehicle deep in space may
be of sufficient intensity and duration to seriously affect men and equip-
ment.

Adequate radiation protection for specific manned missions and exposure
times will require design studies to determine the optimum combination
of structural materials and placement of supplies and equipment surrounding
the crew. Materials of low or intermediate atomic weight (such as Beryllium
or Carbon) are most effective in reducing ionizing particles incident upon
vehicle walls (electrons, protons and primary cosmic radiation). Hydro-
genous materials provide effective shields against the neutron flux from
a reactor propulsion unit, as well as the neutrons produced when high-energy
particles are attenuated in vehicle walls. Low density fuels, water, food,
or other supplies and equipment of low specific weight, if strategically
placed within the space vehicle can be used to augment any structural
shielding that may be necessary. (Radiation levels high enough to produce
significant activation of food and water can be expected to be lethal to man).

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The requirement for high density materials such as lead, uranium, etc. to reduce the gamma or X-ray dose within occupied space will be considerably modified if the heavier shielding is used only to enclose the least volume in which a man can function effectively, such as a single compartment, or even individual capsules. Such temporary protection may be necessary in passing through the inner Van Allen Belt on escape trajectories; through brief, intense storms of solar particles; or Argus-type radiation, artificially injected and trapped in magnetic fields. In the case of nuclear powered vehicles, direct and scatter gamma radiation produced during the propulsion and shut-down phases can be well enough estimated so that shielding analysis will include shaping techniques, and shield orientation for the temporary protection required for crews. A number of applicable studies, conducted by Convair-Ft. Worth are referenced in the bibliography.

2. Separation

Reactor-crew compartment separation distances for thrust versus dose rate (unshielded) have been estimated by various authors. Representative graphs for direct and scattered radiation from a powerplant are given in a number of reports (*) and can be used as a first step in nuclear shielding analyses.

C. Methods of Meteorite Protection

Several methods have been proposed for the prevention of meteoroid puncture of surfaces of space vehicles. The best known of these are the following:

1. The Bumper Concept

This idea, originally proposed by Whipple, employs the basic concept that a meteorite explodes as it contacts the bumper surface, with the resultant dispersing of its energy over a large area of the primary surface to be protected. This technique provides one of the lightest and possibly most effective methods for protection against meteorite hazards.

2. Massive Resistance Technique

In this method the thickness of the primary skin of the vehicle is increased to the extent that the probability of a penetration is arbitrarily reduced to a small magnitude.

3. Self-Sealing Technique

Silicone-based plastic materials are utilized for instantaneous sealing of meteorite punctures. Commercially available silicone-based plastics have a temperature limit for sustained exposure of about 550°F. A self-

(*) Konecci, Eugene B. and Trapp, Robert, "Calculations of the Radiobiologic Risk Factors in Nuclear Powered Space Vehicles", Aerosp. Med. Vol. 30: pp. 487 - 506, July 1959.

Trapp, Robert and Konecci, Eugene B. "Shielding and Nuclear Propulsion", Douglas Aircraft Company Engineering Paper 806, Missiles and Space Systems Engineering, Santa Monica Division, July 1959.

sealing space vehicle skin is expected to weigh about 0.8 lb/ft^2.

4. **Slurry Fluid Technique**

In this method, which has been under experimental study at the Electro-Optical Corporation, minute metallic balls in a fluid are circulated next to the cabin outer skin. Some of these metallic balls are supposed to rush to any puncture caused by meteorites and plug it.

D. **Other Hazards and Protective Measures**

1. **Fire Hazard**

Very little work has been reported in the literature relating to the study of fire hazards in space vehicles. However, the results of considerable efforts by the aircraft industry to minimize fire hazards aboard airplanes may be readily applicable to space vehicles. The factors which contribute to fire hazards include cabin atmosphere composition, partial pressure of the component gases and total pressure. The nature of equipment on board and the materials used are also significant.

2. **Cabin Leakage**

One of the most critical problems of space flight is the loss of cabin atmosphere by leakage and consequently the loss of the crew's life-sustaining oxygen. Holes or minute cracks in the cabin walls may result from meteorite punctures, thermal stresses or mechanical forces associated with launching and recovery of the vehicle as discussed above. Puncture of the vehicle's skin may also result from other accidental hazards, or from hostile enemy actions. It is noted that many of the mentioned cracks may be very minute and will thus be exceedingly difficult to locate until a substantial amount of the cabin gas has been lost. The rate and extent of the loss of confined atmosphere will depend on such factors as the volume of the space cabin, the area of the hole or crack, and the pressure differential between the cabin and its external environment.

Measures for protection against cabin leakage include the following:

(a) Means of detection and monitoring of punctures so that instantaneous repair measures can be undertaken.

(b) Make-up of lost atmosphere should be initiated once a puncture occurs. It is noted that a high pressure cabin allows for a greater decompression time and thus permits more time for effective emergency measures to be taken. Make-up gas should be composed of both oxygen and a diluent gas. If only oxygen is supplied in case of such emergency its concentration in the atmosphere will constitute a fire hazard.

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(c) Compartmentation, whereby the damaged compartment may be sealed off from other parts of the vehicle, constitutes a good protection method in case of leakage.

(d) Space suits should be provided to be worn in case of cabin decompression.

(e) Preventive methods, such as the use of a meteorite bumper, the massive resistance, the fluid slurry and the self-sealing techniques discussed above should be considered.

3. Disabling Failure

It is recognised that without an escape system of exceedingly high reliability no manned space flight could be planned in the next few years. In the Mercury Project, for example, an escape system exists consisting of a tower and an escape rocket attached to the capsule. In case of failure the escape rocket pulls the capsule away from the booster. The tower and capsule then coast until they slow down. Hence, the tower is jettisoned and a parachute is deployed.

Some of the immediate missions are planned with the crew riding a Mercury-type capsule during the launch and recovery phases. Rescue from such vehicles will thus be similar to the Mercury capsule. Rescue from more advanced vehicles will have to be attempted through the use of secondary vehicles. The design of these vehicles will have to include effective means for the transfer of the occupants to the rescue vehicles through emergency air locks and doors. Ehricke recommends the use of secondary propulsion systems, navigation system and auxiliary power system.

Space suits and the compartmentation technique should also be considered for use during emergency conditions.

E. Cabin Structural Requirements

Placing a man in orbit and returning him safely to Earth imposes some extreme structural requirements on the space cabin design in order to protect him against both the hostile environment and the mechanical loads associated with launching and recovering the vehicle. The following requirements have to be met by the cabin:

1. To protect the internal atmosphere and guard against its loss.

2. To act as a shield against thermal stresses.

3. To protect against acoustical noises and vibrations.

4. To withstand the launch, re-entry and landing forces.

5. To shield against meteorites and space radiations.

6. To provide ample living and working space for the crew.

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An intricate cabin structure will thus have to be provided to meet all of these requirements. A composite structure is proposed which consists of an outer shell, radiative insulation layers that act also as meteorite bumpers and an inner shell.

The outer shell will have the following requirements:

1. To support and protect the inner shell.

2. To provide thermal and acoustical protection.

3. To act as a meteorite bumper.

4. To provide means for entering and leaving the cabin, for both normal and emergency operations, through the use of some kind of air locks.

5. To provide means for outside observation through direct or indirect windows.

6. To provide radiating and ablative surfaces.

The inner shell will constitute a sealed pressure vessel and will be capable of meeting the following conditions:

1. To provide living and working space for crew and equipment.

2. To carry no external load but will transmit internal loads to outer structure.

3. To be resistant to explosive decompression in case of puncture.

4. To be as independent as possible of all the thermal and structural stresses of the outer shell.

5. To avoid leakage regardless of the mechanical forces imposed upon the vehicle during boost, re-entry and landing phases.

Figure 11 is a schematic representation of a proposed cabin wall structure, showing the radiative insulation layers placed between the inner and outer shells.

Manned re-entry vehicles may be either of a ballistic type, with a low weight to drag (W/C_DA) ratio or of a glide vehicle type with moderate lift to drag $(\frac{L}{D})$ ratio. Both will have low entry path angles. It is estimated that the deceleration forces will be of the order of 10g for ballistic vehicles and about 1g for the glide vehicle. Neither of these will pose any extraordinary structural design problems.

PROPOSED CABIN WALL STRUCTURE
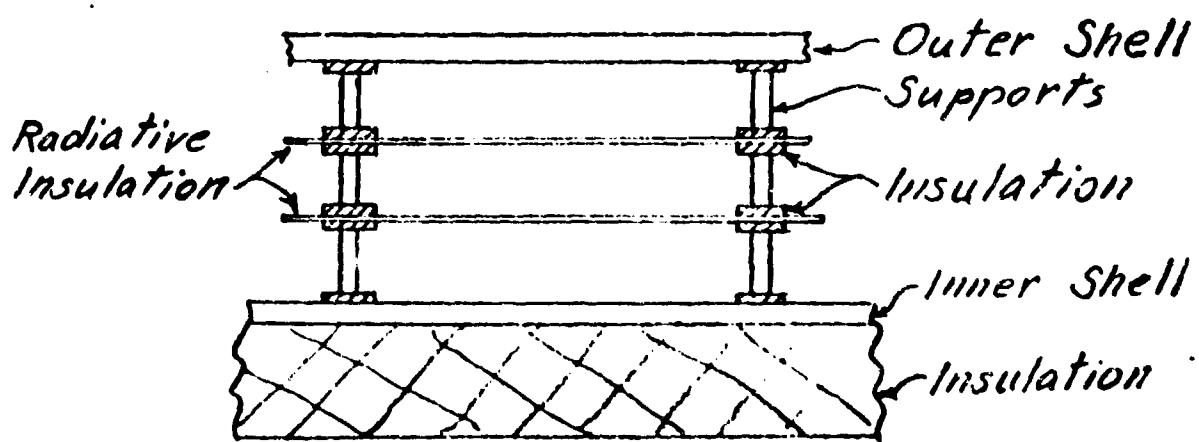
Multiple layers function as meteoroid bumpers.

FIGURE 11

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The thermal stresses associated with the vehicle's launching and recovery, due to aerodynamic heating, are quite severe and will consequently impose restrictions on its structural design. A ballistic type re-entry vehicle should withstand a high rate of heat input. An ablative shield is usually used with such a vehicle as a heat sink. A glide re-entry vehicle is exposed over its major area to a smaller heating rate and a much larger total heat input than a ballistic type vehicle for the same flight. A glide re-entry vehicle may necessitate the use of a radiative cooling structure possibly like the one shown in Figure 11. It should be noted, however, that in such a structure the temperature of the outer shell will be considerably greater than the temperature of the inner shell. Thus, a great amount of differential thermal expansion between the two shells is to be expected. Cracks in the cabin walls resulting from these thermal stresses may lead to the loss of the cabin atmosphere. The following precautions are advantageous when designing a radiative cooled structure.

1. Select low expansion materials for the outer shell and high expansion materials for the inner shell.

2. Use closely spaced supports to spread out buckling resulting from thermal stresses.

3. Use very low interior surfaces emissivities.

4. Minimize conduction paths between outer and inner shells.

5. Segment the cuter shell if this is not structurally objectionable.

Last, it should prove very fruitful to study the effects of the following parameters on the structural weight of the cabin:

1. The geometrical form and volume of the vehicle.

2. The characteristics of the payload.

3. The number of the crew.

4. The mission duration.

A. Atmospheric Pressure and Composition Control

1. Gas Storage

An oxygen supply will have to be provided for vehicles using non-regenerative ecological systems. A relatively smaller amount of oxygen will also be needed for make-up and emergency conditions when a regenerative oxygen system is employed.

Oxygen will be stored in a gaseous or cryogenic form, or possibly generated chemically. Gaseous oxygen systems, with reliable equipment already developed, are light and simple to control, and will thus be desirable for short duration missions. LOX will probably be provided in double walled containers weighing about $1\frac{1}{2}$ times the weight of LOX for missions of the order of 1 to 3 man-weeks. LOX systems could also be used as heat sinks for the cooling systems. Oxygen may be generated chemically by the decomposition of hydrogen peroxide which requires a relatively simple storage system weighing as little as one sixth the weight of H_2O_2. Hydrogen peroxide systems may also produce water for consumption and power generation. Provisions should be made for the storage of other gases such as inert gases for the cabin atmosphere and propellants for attitude control systems. O_2 generation from superoxides of the alkali metals, such as KO_2, is a promising technique which has the added attraction of CO_2 absorption ability.

2. Carbon Dioxide

The problems associated with the treatment of CO_2 in the cabin atmosphere include the processes of its separation from the circulating air and the subsequent disposal of it or its reduction to carbon and breathable oxygen.

    (a) Removal of CO_2. Different methods have been introduced to remove CO_2 from the cabin air. It should be noted that some of these methods include both the removal and reduction of CO_2 to carbon and oxygen. The methods introduced include the following:

        (1) Venting: For short duration missions of very few hours one might resort to venting of the cabin atmosphere periodically.

        (2) Membranes: Semi permeable membranes are available which pass different kinds of gases at different rates. Some which are permeable to CO_2 could be used to filter it out of the cabin atmosphere.

        (3) Freeze-out: Here the cabin air is to be cooled to a low temperature. This results in the gases being separated from the air in a solid or liquid form. CO_2 is then removed by cyclic purging or evacuation.

(4) Electrolysis:

    a. A sodium sulfate electrolytic cell is utilized to reduce water to H_2 and O_2. This results in sulfuric acid at anode and sodium hydroxide at the cathode.

    b. Carbon dioxide is then absorbed by sodium hydroxide forming sodium carbonate.

    c. Sodium carbonate is later allowed to react with sulfuric acid releasing CO_2 to be disposed of, sodium sulfate is also formed and is then returned to the electrolytic cell.

    d. The cycle is then repeated.

(5) Chemical Absorption: Various chemicals may be used to absorb CO_2 from the cabin atmosphere. These include lithium hydroxide, baralyme, soda lime, potassium superoxide, alkanolamines and alkali carbonates. Further study should be directed to development of chemical absorbers that could be reactivated and re-used. They are more desirable since they impose a lesser weight penalty on the system. The monoethanolamine (MEA) solution, for example, chemically absorbs CO_2 and other acidic gases and then, when heated to about 150°F, releases CO_2 and becomes ready for re-use.

(6) Water Absorption: Water could be used to absorb a moderate amount of carbon dioxide which is to be released later by heating that water.

(7) Absorption: Some absorbants, such as the Linde molecular sieves, which absorb certain gases without a chemical reaction and then release them on heating, could be used to remove CO_2 from the cabin atmosphere.

(8) Carbon dioxide can also be removed either by condensation by compression and cooling, or by compression followed by a Joule-Thomson expansion. These two methods however require heavy machinery and should be ruled out for space applications.

(9) Photosynthetic Methods: Regenerating oxygen from CO_2 and wastes in a closed ecological cycle does not promise to become practical for use in space ships for at least ten more years.

(10) Photolysis: This method, wherein CO_2 is decomposed to yield oxygen by means of ultraviolet light and a catalyst still has to undergo considerable amount of development.

(b) Reduction of CO_2. While the above mentioned methods deal primarily with removing CO_2 from the cabin atmosphere, some methods deal exclusively with the reduction of CO_2 after its separation from the cabin atmosphere. The most promising of these processes is the one

utilizing hydrogen to chemically reduce CO_2 and give carbon and water, plus the electrolysis of water to give hydrogen and oxygen. Hydrogen is then recycled for the reduction of CO_2. This process is under experimental study at the Battelle Memorial Institute for WADD's Aero Medical Laboratory. Other processes for the reduction of CO_2 include its thermal decomposition to carbon and oxygen. This process does not seem possible by methods feasible for a space cabin since it requires excessive power.

Reduction of CO_2 by irradiation by gamma rays does not look attractive for space applications due to large weight penalties and low process efficiency.

Photochemical and photosynthesis methods have been mentioned above.

3. Odors and Trace Contaminants

The cabin atmosphere will be continuously contaminated with odors emanating from the human body and from electrical and mechanical equipment in the cabin. Human odors present will consist primarily of indole, skatole, flatus, hydrogen sulfides, amines and glandular excretions. Toxic or unidentifiable gases may be generated from overheating or other malfunctions of the mechanical or electrical systems. Traces of carbon monoxide and other noxious gases will also be present in the atmosphere.

Activated charcoal filters, to be placed in the circulating air stream are good absorbers of many of the organic gases contaminating the atmosphere. Electrostatic precipitator odor collectors should be considered for long duration missions and when the electrical power required for their operation is readily available.

B. Food, Water and Waste

1. Water Supply and Reclamation

The average human body demands a daily water supply of about 2,200 cc, or approximately 5 lb. About 14% of this amount leaves the body by respiration and 20% is lost by perspiration. The urine accounts for 60% of the body water requirement and the remaining 6% leaves the body in fecal compounds. However, an additional amount of water, namely metabolic water, is formed within the body from the oxidation of the hydrocarbonic food constituents. Metabolic water is formed at an average rate equal to 14% of the body daily requirement. Thus, if water is reclaimed from cabin atmosphere and from urine, while feces is disposed of either by storage or jettisoning, then an additional 8% of the water intake is formed by a partially closed ecological cycle.

(a) <u>Water Reclamation</u>. Water reclamation is accomplished by collection of atmospheric moisture and by processing of urine and wash water.

(1) Collection of cabin atmospheric moisture: Numerous schemes could be utilized to reclaim moisture from the cabin atmosphere. These include the following:

a. The use of either surface condensers or water sprays to cool the cabin air below its dew point and the collection of its water content.

b. Compression of cabin air until the water's partial pressure exceeds its saturation pressure.

c. Combined compression and cooling of the air.

d. The absorption of moisture in spray chambers using organic liquids such as glycerin or solutions of salts such as lithium chloride.

e. The employment of counter-current flow of the humid air and sulfuric or phosphoric acids.

f. The utilization of chemical absorbents such as NaOH.

g. The use of insoluble solid desiccants such as silica gel.

A method for the collection of a space cabin's atmospheric moisture which avoids some problems of zero gravity and power consumption is by the use of regenerative desiccants. Insoluble solid desiccants include calcium oxide, dreirite, barium oxide, activated alumina, silica gel, Linde molecular sieves, and magnesium perchlorate. Soluble desiccants include lithium and calcium chlorides, and sodium and potassium hydroxides. In some cases regeneration is possible by heating the desiccant and condensing the water vapor evolved

Direct condensation of atmospheric moisture is relatively simple; and is particularly attractive if a cold source, such as a cryogenic fuel or oxygen supply, is already on board. Another method is the use of a radiator-condenser which rejects heat to space and is designed for operation at temperatures below the dew point of the cabin atmosphere.

(2) Reclamation of Waste Water: Waste water is composed mainly of wash water and urine. Most of the methods used in processing urine seem to be applicable to all kinds of waste water. Since urine is the chief source of water supply it seems that one of the most important life-support subsystems that has to be developed is the one required for the treatment of urine in a closed ecological system. Such a unit seems to be technically feasible, however the amount of research done to substantiate the predictions of the performance of such a device is very sparse.

Some of the methods suggested for the reclamation of water from urine follow:

a. Freezing: In this method water is allowed to freeze out of solution leaving the impurities behind. Methods suggested for freezing include space radiation and mechanical refrigeration.

b. Electro-Osmosis: Here the water container is divided in three compartments by two types of sieve barriers. One of the barriers is permeable only to positive ions while the other is permeable only to negative ions. When the walls of the container at either end are electrically charged ion concentration increases in the end compartments and the ion-free water formed in the middle compartment is drained off.

c. Chemical Methods: Several chemical methods have been proposed for water reclamation from urine. One of the more promising chemical methods is the one utilizing the principles of ion exchange. New synthetic resins developed in the past few years are found to have a high degree of ion exchange ability. In this process minute spherical granules are made to remove selectively any or all of the iors in urine and produce water that is practically free of electrolytes.

d. Distillation: In this process urine is evaporated and then the water vapor is allowed to condense. For space application, urine could be heated and centrifuged simultaneously, then allowed to condense in a space radiator. The condensate is then filtered. The use of a microfilter before processing is recommended to remove bacteria, large protein particles and other suspended materials. Vacuum-distillation will reduce the heating power requirements.

(b) Water Supply. Initial water has to be supplied for short duration missions as well as for make-up for partially closed ecological water systems. This water will be supplied either as liquid or in a chemical compound.

The possibility exists that this water while in storage could be used for radiation shielding.

2. Food Preservation

For mission durations of more than a very few days it is desirable for the morale and health of the crew to provide food that is high in quality and varied in form.

Methods of food preservation should insure long storage life with light packaging requirements. The following methods have been suggested.

(a) **Canning.** In this method bacteria are killed and enzymes deactivated by heat. Canning preserves food for long durations. However, its packaging might require higher weight penalties than other methods.

(b) **Freezing.** In this process the low temperature inhibits bacteria growth. High consumer acceptability, medium packaging requirements, and long preservation life are insured. However, these are offset by the heavy power demands of a freezing system with its associated high weight penalties.

(c) **Freeze drying.** In this method, food is first frozen and then subjected to a pulsed electromagnetic beam until the ice crystals are sublimed. In this process the food is reduced to about 10% of its original weight. Bacterial growth and formation of enzymes are inhibited by the absence of moisture. Vitamins and protein structure are not affected. This method has a long storage life and light weight. However, it has a critical packaging problem. The presence of as much as 2% moisture, by weight, will cause browning of the food. Greater moisture contents will activate enzymes and bacteria.

In preparing a frozen-dryed food for consumption it requires soaking in water for varied periods of times to regain its moisture content.

(d) **Beta and Gamma Irradiations.** In this method food is preserved for long duration when subjected to beta and gamma irradiations which inhibit sprouting and destroy the microorganisms and parasites present. This method increases the storage life of meat and produce, and if sterilization is possible no refrigeration is needed. However, only few items can be irradiated without producing bad tastes, colors or undesirable odors.

3. Waste Products

Wastes include urine, wash water, food wastes and feces. For a mission duration longer than a few days, urine and wash water will have to be processed to reclaim water from them. Feces contain about 0.2 pounds of solids per average man per day together with 0.3 pounds of water. It seems that for the next few years it will be more advantageous to store this kind of waste, while the vehicle is in orbit, than to reprocess it or even jettison it overboard. Waste products will be recycled whenever a completely closed ecological system is developed.

C. Closed Ecological Systems

Closed ecological systems have been proposed which utilize the concept of biological balance between animal and plant lives. The process involved _s the synthesis of carbonhydrates through the action of chlorophyll with the aid of solar radiation. This process is known as photosynthesis and can be characterized by the following relation:

$$6CO_2 + 6\ H_2O + \text{Solar Energy} + \text{Chlorophyll (Catalyst)}$$

$$= C_{16}\ H_{12}\ O_6 + 6\ O_2$$
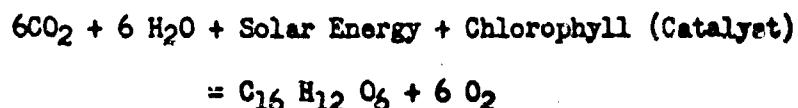
Considerable energy is needed in this process since it involves breaking the chemical bonds of the H_2O and CO_2 molecules. It is also noted that the absorption band of chlorophyll lies between 0.4 and 0.75 microns which means that only about 35% of the solar energy can be used in the process. This portion of solar energy will be even reduced further by the processes of plant respiration and other deficiencies in the plant's systems. Konecci estimates that only 20% of the solar energy is utilized in photosynthesis.

Proposed closed ecological systems include algae and broad leaf plant systems and some introduce animal life in the process by the inclusion of fish or other animals. Algae systems would utilize human wastes in either a gaseous, liquid or solid form as nutrients.

Long range planning for adaptation of algal culture systems to future space cabins has been undertaken by the USAF School of Aviation Medicine. Experimental research in this area is conducted by many organizations including The University of Texas, The University of California at Berkeley, The National Institute of Health, Electric Boat Division of General Dynamics and Boeing Airplane Company.

It is estimated that in a period of about ten years a prototype closed ecological system may be developed.

D. Related Subsystems

Systems related to the life support and environmental control include auxiliary power and other thermodynamically related subsystems such as attitude control, propulsion and all equipment which uses auxiliary power.

This relationship exists by reason of the heat rejection of the auxiliary power system and all power using equipment, and the relationship may be augmented by design of integrated systems.

The auxiliary power system will be required to supply the power demands of the life support and environmental control system as well as that for communications, reconnaissance, guidance, attitude control and other power consuming units.

Analyses have shown that the life support and environmental control system will require more than 50% of the total auxiliary power. Thus the selection of a power system will influence the performance of most of the space vehicle's subsystems. Auxiliary power systems for manned space craft may be nuclear, solar or chemical. Methods of systems integration are described in the following paragraph.

E.   Integration of The Life Support System with Other Vehicle Subsystems

It is evident that for the design of an overall optimum space vehicle some degree of integration will be considered between the life support and environmental control systems and any other thermodynamic systems such as the auxiliary power and attitude control systems. It is also apparent that each individual vehicle will present new problems and require new solutions and thus no one solution or a series of solutions will be suitable across the board.

Relatively short duration missions offer the best promise for system integration such as when the thermal and environmental control systems are integrated with the hydrogen-oxygen power system. For longer duration missions, food, water and cryogenic stores may be used for shielding against radiation.

As a typical example of systems integration consider the NASA-planned Nova Lunar Reconnaissance Mission. This is a direct Earth-to-Moon flight taking 2 men to a soft landing on the moon and returns in about 12 days. The following are rough estimates of the power requirements for such a mission:

Attitude control, guidance, reconnaissance, telemetering and other
electronic equipment   = 1,000 watts

Environmental Control Systems:

1. CO_2 Separation and Removal   =   400 watts

2. CO_2 Reduction with Hydrogen to Carbon and Oxygen,
    including power for water electrolysis and
    oxygen make-up   =   840 watts

3. Urine Water Distillation   =   200 watts

4. Toxins and Dust Removal   = __400 watts__

                                            Total   2,840 watts

                              or Approximately   3,000 watts

Now the minimum amount of oxygen needed by the crew for the mission is approximately 48 pounds. Thus, considering an additional 24 pounds for emergency and make-up conditions and allowing for tankage and storage, the total weight of the oxygen supply system would be about 180 pounds.

About 240 pounds of water will be needed for the mission. Thus the water storage system, if fresh water is taken on board, will be approximately 300 pounds. Various power systems can be utilized for such a vehicle. These include nuclear reactors, solar power systems, hydrogen-oxygen power systems, hydrogen peroxide systems and hydrogen-oxygen fuel cell systems. If nuclear or solar energy sources were utilized it seems advantageous to carry the required oxygen and water on board and supply the required power for the other systems.

When a chemical hydrogen-oxygen system is utilized a 1.8 KW system will be required. This system will demand an assumed specific propellant consumption of 1 pound/HP-HR. The water formed in the combustion process will be = 695 pounds. 240 pounds of water will thus be available for human use and the remaining, as water vapor, could be used for attitude control and propulsion purposes. The cryogenic storage system may also be used as a heat sink for the environmental control system.

It does not seem beneficial to use a hydrogen peroxide system since it would be too heavy for this particular application.

A hydrogen-oxygen fuel cell system may also be applicable to this mission. Water is a by-product of these cells but it will have to be purified to make it potable. The present state of development of fuel cells make it difficult to assess the advantages of such a system. A system weight of 800 pounds per kilowatt is estimated for this application.

IX. SURVEY DATA

A major portion of the first quarter effort has been a survey of current technology. Section XII, Bibliography, indicates some of the literature available. Visits were made to several government establishments and industrial firms, including other Divisions of Convair, to determine the nature and scope of their work in environmental control.

A. Summary of Visits

Following are brief comments about results of visits. Not all places were visited by the same personnel. More detailed information is available in trip reports of the visitors.

1. Aerospace Medical Center, Brooks AFB, San Antonio, Texas. The Space Medicine Division of this center is primarily concerned with basic and applied research, with attention to hardware development only as necessary to accomplish research. Current and planned programs are medically oriented studies, which include: effects of various cabin atmospheric compositions and pressures; trace contaminants; neuro-psychiatric effects of the space environment; and bacteriological problems in water regeneration from urine.

2. USAF Ballistic Missile Division, Inglewood, Calif. BMD has a small Bio-Astronautics staff, all of whom are Air Force officer personnel. Past work dealt with animal experiments in ballistic missile flights, and at present there is an unofficial status as advisors on the Mercury program. Their experience indicates that manned space flight is being paced by life support equipment and not by booster capability.

3. The Rand Corp., Santa Monica, Calif. Recent Rand studies include one on the meteoroid hazard to manned space flight. Another is on oxygen reclamation by reducing CO_2 with hydrogen, followed by electrolysis of the water. They are negotiating with a vendor source for an experimental phase of this study.

4. NASA, Washington, D. C. At the time of the visit, the reorganization which created the Office of Life Sciences had not been accomplished. Dr. Douglas Worf, then Chief of the Biology and Life-Support Systems of NASA, recommended that Convair re-submit, at mid-1960, the proposal "Life Support Systems Design Study for Manned Space Vehicles", dated 8 September 1959. (REA 8349). A later letter from NASA indicated a lack of funds and suggested that the matter be brought up again next year.

5. WADD, Dayton, Ohio. PR 92069, written by the Aeronautical Accessories Laboratory, is discussed in Par. IX C. 1. The Aero-Medical Laboratory-Engineering Development Branch has the following work in progress under Laboratory sponsorship.

   a. University of Dayton - CO_2 concentration and recovery methods.

   b. Battelle Memorial Institute - Recovery of O_2 from CO_2 - Reduction of CO_2 with Hydrogen.

c. Chemical supply of O_2 using potassium superoxide - In proposal stage.

d. Development of regenerative absorbers for CO_2 and H_2O.

e. Electrolysis of H_2O at zero "g" to produce oxygen.

f. Storage and control of liquid O_2 at zero "g" - Diaphram or bladders and paramagnetic properties of LO_2 are being studied to separate the liquid and vapor phases.

g. Storage of gaseous O_2 - 7500 psi appears to be the optimum pressure—criteria is pressure for which product of weight and volume of container is minimum

h. Liquid oxygen converters - methods of heating to regulate vaporization rate

i. Continuous monitoring of gaseous environment composition - studies at Lab

j. TAPCO - Development of combination fuel cell and O_2 source

k. Firewel Co. - 6 hour knapsack O_2 and cooling supply for space suit

l. Stewart-Warner - "Liquid look" water absorber

m. Electric-Boat Division-General Dynamics Corp. - Algae experiments to develop closed ecological cycle - Aero-Med Lab does not appear to be as enthusiastic about this method as was Electric Boat (Dr. Richard Benoit). No reports are yet available.

n. Electric Boat - Water reclamation studies - Reports not yet available. Vacuum distillation of urine appears to be most promising at this time. Freezing purification of urine is not proving out.

o. Artificial photosynthesis methods studies - Contractor not yet selected. Use of the Hill reaction, wherein light is used to energize the reduction of H_2O to H_2 and O_2, is to be investigated.

p. Nutritional studies of algae - Boeing is doing work in this area, as well as the Aero-Med Lab.

q. Use of animals, as well as plants, in balancing closed ecological systems

r. Processing of human waste by use of algae - Techniques for use of algae to consume and convert wastes are still in very early stages, again contrary to information obtained from Electric Boat.

s. General Electric - Food Refrigeration space vehicles.

6. Electric Boat Division, General Dynamics Corp., Groton, Conn. Electric Boat has extensive facilities and a relatively large organization devoted to environmental control studies. Much work is on algae cultures for photosynthetic gas exchange, waste processing, and food production. Other investigations include electrolytic oxygen generation, removal of trace contaminants from air, oxygen supply from metallic superoxides, and CO_2 removal by freeze-out. Part of their work is for Hamilton Standard Division of United Aircraft. They seek cooperative efforts with Convair.

7. Garrett Corp., Los Angeles, Calif. The AiResearch Division produces the life support system for the Mercury capsule. This is a system having 7500 psi oxygen supply which is reduced to 100 psi and then to 5 psi for both the capsule and the pressure suit. The recirculation system has blowers, a charcoal filter, a lithium hydroxide absorber for CO_2, and a water vapor condensor with sponge and squeeze apparatus for zero - g operation. Cooling is by evaporating water from a tank. They are proposing a cryogenic system to replace gaseous oxygen storage.

8. Litton Industries, Beverly Hills, Calif. A research program on high vacuum friction has been completed. Litton prepared for Aerojet the life support and human factors portion of a report, "SR-192, Strategic Lunar System", AFBMD TR 60-16, Contract No. AF 04(647)-333. They have proposed a moon base simulator for training space crews to work on the lunar surface.

B. Industry Activity in Environmental Control

   In addition to the information by visits, various literature sources and personal contacts indicate activities of competing firms as outlined below.

1. Boeing Airplane Company. A Space Medicine Branch is organized under the System Engineering Directorate, and the Branch has an Environmental Protection Section. Representative areas of work include cabin environment, pressure suits, toxicology, radiation effects, noise, vibration, acceleration, environmental recycling apparatus, safety equipment, and physiological instrumentation. Among present facilities are a microbiological and biochemical laboratory, an animal colony facility, a greenhouse, an electronics shop, and a radio-isotope laboratory. A proposed biological research facility will include altitude and decompression chambers equipped for multiple-stress testing of equipment and personnel. Boeing has environmental protection experience on the Dyna Soar program and was also a funded contractor on SR-183. They are scheduled to conduct a low frequency vibration test on crewmen for a Navy research program.

2. Douglas Aircraft Company, Santa Monica, Calif. Life support and environmental control systems for 3-man and 5-man space stations have been designed. The occupancy duration is 100 days and there is provision to accommodate up to 15 crewmen for periods of a few days for training. Douglas estimates cost to develop this station, exclusive of Saturn Booster, is $100 million. This comprehensive and up-to-date study

is a continuation of extensive activities over the past several years, including studies of space cabin design and human factors requirements. A Life Sciences Section performs the current work. Douglas participated in SR-183 studies on a company-funded basis and was recently awarded a contract for development of the Saturn second stage.

3. Chance Vought, Dallas, Texas. A Human Factors Laboratory is equipped with earth-orbital simulators and space capsule mock-ups. Closed ecological systems are under study. A proposed simulator would duplicate heat, movement, noise, and many of the psychological effects of space flight. Chance Vought Astronautics has designed a manned space station using Saturn as Booster, with predicted cost of $1.5-2.0 billion, exclusive of booster and launch facilities.

4. McDonnell Aircraft Corp., St. Louis, Mo. Design and fabrication of the Mercury manned capsule is the principal effort in manned space flight. The environmental control system was designed by McDonnell and is being built by AiResearch.

5. North American Aviation, Inc., Los Angeles, Calif. Environmental control experience is associated with the X-15 program and company funded work on SR-183.

6. Lockheed Aircraft Corp., Missile and Space Division, Palo Alto, Calif. Lockheed has proposed a 10-man, wheel-shaped space station for research purposes and later a $1.5 billion modular building block type of space station of indefinite life using the Saturn booster. These proposals indicate considerable detailed effort in the manned vehicle field.

7. The Martin Co., Denver, Colorado. Studies of an advanced lunar base have been made, including funded contractor work on SR-183. Martin - Baltimore has also designed a Saturn boosted multi-manned space station using present state-of-the-art in structures and environmental control.

8. United Aircraft. The Hamilton Standard Division, Windsor Locks, Conn., has studied and proposed evaluation of five carbon dioxide control systems. Other studies are on temperature control of space cabins. United Aircraft also participated in SR-183 studies on company funds.

9. Others: Minneapolis-Honeywell built the 2-man space cabin simulator for the AF School of Aviation Medicine and made lunar base studies. American Machine and Foundry has studied water recovery by distillation of urine. Air Reduction Co. has worked on an experimental closed-cycle breathing ventilation system. Firewel-Aro Co. is studying atmospheric control and cooling of space suits and cabins.

C. Current Activities of Government Agencies

Environmental control is and has been an essential part of all space programs. Those involving manned flight have requirements of broader scope and these problems are being recognized in current activities of NASA and the armed services.

1. <u>Space Vehicle Thermal and Atmospheric Control Study.</u> PR 92069, from the Aeronautical Accessories Laboratory, WADD, Dayton, Ohio calls for an analytical and experimental study of environmental control of man and equipment in future military space vehicles. Convair's proposal is contained in Report No. ZR-760-016, March 30, 1960.

2. <u>Manned Space Flight.</u> The Mercury project is well known. There are indications of interest in an advanced version having longer flight duration and greater crew capacity. SR 79814, "Space Logistics, Maintenance, and Rescue" (SLOMAR) deals with the study of space ferry vehicle design, including environmental protection and life support for short duration flights. SR 17527, "Military Test Space Station", involves similar requirements for durations of several weeks and with a crew of several persons.

3. <u>Lunar Base.</u> An Air Force team made a concentrated study of life support and environmental control in connection with SR-183 on lunar basing. Conclusions were:

   (a) Pressure suits will not be worn in normal operations within vehicles.

   (b) Cabin atmosphere will be air at 14.7 psia.

   (c) System will not be dependent on biological components (algae).

   Another lunar base study is SR-192, and reports have been prepared but not released.

4. <u>NASA.</u> Among NASA studies is one of an 8-man Mars exploration mission, in which 24% of the 350,000 lb. vehicle weight is allocated to food, water, and oxygen. Current emphasis on these and related problems is shown by the creation of the Office of Life Sciences at a level immediately subordinate to the NASA Administrator.

X. PROBLEM AREAS

Nearly all aspects of environmental control and life support involve problems which must be solved if progress in manned space flight is to be maintained. Some of these problems can be circumvented, or partial solutions exist. Others will require basic research for adequate results. Technical aspects of these problems have been discussed in sections VI, VII, and VIII. The purpose of further discussion here is to indicate the type of effort required and the relationship to missions planned.

A. Summary of Problems

Problems	Type of Effort	Relationship to Missions
1. Thermal control	Analyses, design, and development.	All missions
2. Meteoroid protection	More research is necessary to adequately define the hazard. Design studies of protective measures.	All missions. The hazard increases with duration.
3. Natural radiation protection.	Basic research is necessary to adequately define the hazard.	The hazard increases with duration. Van Allen radiation may be avoided by choice of trajectory.
4. Leakage of cabin atmosphere.	Analyses, design, and development of cabin structure.	All missions. The hazard increases with duration.
5. Storage of atmospheric gases.	Analyses, design, and development.	Short duration missions for primary supply. All missions for emergency supply.
6. CO_2 separation	Research and development. Seek new physical and/or chemical processes.	Present methods are acceptable for short durations only.
7. CO_2 reduction	Research and development. Seek new physical and/or chemical processes.	Long duration missions will require reclaiming O_2 from CO_2
8. Odors and trace contaminants	Research is required to define the hazard. Control methods are known, but more testing is needed.	The hazard increases with mission duration and may be dependent on other subsystems of the vehicle.
9. Water Supply	Design and development.	Missions exceeding a few man days will require reclaiming water from wastes.
10. Food supply	Basic research in closed ecological systems. Development of preservation, packaging, storage, and preparation methods.	Interplanetary missions, or a permanent lunar base, may require reclaimation of food from wastes. Shorter missions can utilize stored solid foods.

Summary of Problems (continued)

Problem	Type of Effort	Relationship to Missions
11. Subsystems integration.	Analyses, design and development.	All missions.
12. Atmospheric Composition and pressure.	Research to determine man's tolerance to alien atmospheres for long durations.	All missions. An optimum composition is less vital to shorter missions.

B. Selection of Problems for Convair Effort

A determination of which problem areas represent desirable tasks for Convair will be based on the following criteria:

1. Solutions will significantly advance the capability for manned space flight.

2. The effort will avoid areas in which work of others is concentrated and solutions appear imminent.

3. The selected problems will be within Convair's capability with present personnel and facilities.

It is recommended that Convair study the problem areas listed below in order to enhance the capability for participating in programs of manned space flight. This selection conforms with the above criteria and promises maximum benefit to Convair for the level of effort required.

1. Leakage of cabin atmosphere: Even minute leaks impose a severe weight penalty for missions of long duration. In addition to those which may result from fabrication imperfections, other leaks may be caused by meteoroid penetration. Some aspects to be investigated are:

   (a) Analysis of effects of cabin atmosphere composition and pressure on leakage penalty.

   (b) Cabin wall design to minimize leakage by such techniques as a multi-layer spaced structure, integral wall sealant materials, and positive seals for access openings.

   (c) Methods of detecting, locating, and sealing leaks by the crew.

2. CO_2 separation and reduction: Separation of CO_2 is essential in any sealed cabin, and reduction is a step toward a regenerative oxygen supply. The methods presently considered are cumbersome and impose large weight penalties. Although improved performance may be expected of methods now under study, new physical and/or chemical processes should be sought.

3. Integration of environmental control and life support with other subsystems: This area has received little attention and appears very promising. One or more analytical models will be described, based on the mission planning stated in Section IV. These analytical models

will constitute the framework for conception and analysis
of integrated subsystems.

4. Modular design of life support and environmental control equipment:
A man-day capacity unit may be postulated for the non-regenerated
stores for life support and environmental control. This concept may
be extended to the associated equipment. An optimum module, of X
man-days, will be sought, and will be referenced to the mission
planning data of Section IV. The module derived will then be applied
to the stores and equipment to provide design data.

5. Power requirements for environmental control processes: A valid
analysis of power required is essential in assessing the various
processes for environmental control. Many present estimates appear
to be inadequately founded. The power required, including the duty
cycle, will be determined from fundamental considerations together
with any available state-of-the-art information.

XI. PROPOSED PROGRAM

The schedule which follows is for an eight months continuation of the present
study. The tasks shown are those selected in the preceding section, plus the
preparation of a proposal to NASA as described in Par. IX A. 4. Quarterly progress
will be prepared at the end of the second and third quarters, and a final report
will be made at the conclusion of the study. The participating groups are
Air Conditioning, Body, Chemistry Laboratory, Human Factors, and Thermodynamics.

PROGRAM SCHEDULE

Month ——→

Tasks:

Prepare proposal to NASA *

Establish design criteria

Cabin atmosphere leakage analysis

Cabin design studies

CO_2 separation + reduction studies

Subsystems integration studies

Modular design studies

Power requirement studies

Progress reports

Final report

Code:
A Air Conditioning Group
B Body Group
C Chemistry Laboratory
H Human Factors
T Thermodynamics Group

* Date to be determined by later contact with NASA.
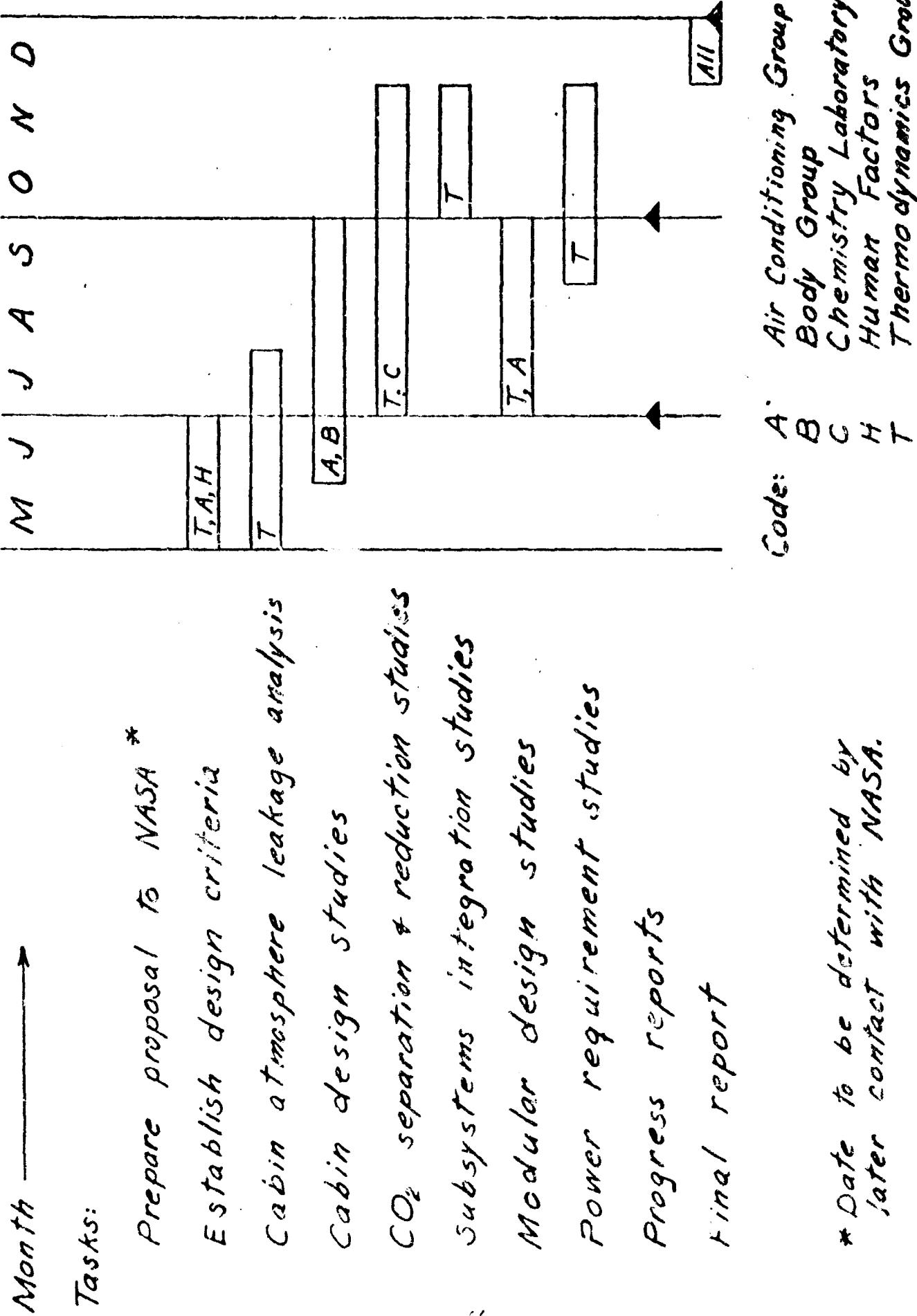
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